

# 2018 PATT36 International Conference

Research and Practice in Technology Education:  
Perspectives on Human Capacity and Development

Editors: Niall Seery, Jeffrey Buckley, Donal Canty and Joseph Phelan

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TECHNOLOGY EDUCATION RESEARCH GROUP

# **36<sup>th</sup> International Pupils' Attitudes Towards Technology Conference**

Athlone Institute of Technology, Co. Westmeath, Ireland  
18<sup>th</sup> – 21<sup>st</sup> June 2018

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# Welcome

Dear PATT36 delegate,

It gives me great pleasure to welcome you to Athlone for the International PATT conference. On behalf of the Technology Education Research Group ([www.TERG.ie](http://www.TERG.ie)) and Athlone Institute of Technology, we are delighted to host the 2018 conference. PATT36 promises to be an informative, innovative, and social gathering that will contribute much to future collaborative and cutting-edge research.

I would like to especially thank the Minister of State for Higher Education, Mary Mitchell O'Connor for her support of educational innovation and enhancement and for opening the PATT36 conference.

Athlone Institute of Technology (AIT) is an award-winning institute that commits to regional impact while maintaining a global focus. AIT is distinguished by its commitment to enhancing the student experience, which aligns with the views of the PATT philosophy. I would like to acknowledge and thank AIT's President, Prof. Ciarán Ó Catháin for his support of both the conference and our research endeavour.

The 2018 conference theme, *'Research and Practice in Technology Education: Perspectives on Human Capacity and Development'* continues to maintain our focus on practice and ultimately enhancing the quality and experience of all Design and Technology pupils. This year, further sub-themes were developed to capture the imaginative, the make, and the impact of our subjects. Each day of the conference will reintroduce the conference sub-themes by highlighting the systemic challenges amplified when attempting to translate research into practice. These plenary sessions will provide useful perspectives and help frame future research discourse and enquiry.

As with all conferences, PATT36 is all about the people – this year, we have delegates from 15 different countries across 5 continents, each making a positive contribution to the broad range of research interests and agenda that will be visited over the four days. The peer review process protects the quality of the conference and with this in mind, I would sincerely like to thank the team of reviewers for their diligence, professionalism, and collegiality during the reviewing process.

Finally, I would like to acknowledge the PATT36 organising committee for their unwavering support and expertise over the past year. It was an absolute pleasure to work with such a fantastic team and a privilege to see first hand, their commitment to enhancing technology education. I thank them most sincerely.

I wish you an inspiring and edifying conference,  
Míle buíochas,



Dr. Niall Seery  
Conference Chair PATT36  
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# Contents

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Rethinking Pupils' Attitudes Towards Technology (PATT) studies <i>Piet Ankwicz</i> <i>University of Johannesburg, Johannesburg, South Africa</i>	1
Woman's under-representation in STEM: The part role-models have played in the past and do we still need them today? <i>Stephanie Atkinson</i> <i>University of Sunderland, Sunderland, UK</i>	9
Changing Competencies, Changing Attitudes? How Teachers Become Technology Teachers <i>Birgit Fahram, Per Norström and Lena Gumaelius</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	16
A Global Analysis of how High School Technology Activities are Preparing Students for the 21st Century <i>P. Scott Bevins</i> <i>University of Virginia's College at Wise (UVa-Wise), Virginia, USA</i> <i>Virginia R. Jones</i> <i>Patrick Henry Community College, Virginia, USA</i> <i>Daniel L. Trent</i> <i>Mississippi Valley State University, Mississippi, USA</i>	23
Technology Teachers' Different ways of Thinking about Sustainable Development in Technology Education <i>Maria Svensson and Ann-Marie von Otter</i> <i>University of Gothenburg, Gothenburg, Sweden</i>	33
What technology content and values emerge in the teaching of climate change? <i>Susanne Engström</i> <i>KTH/ITM Royal Institute of Technology, Stockholm, Sweden</i>	40
Technological Thinking by Children with Special Needs <i>Michal Levi</i> <i>Tel Aviv University, Tel Aviv, Israel</i> <i>David Mioduser</i> <i>Tel Aviv University, Tel Aviv, Israel</i>	47
Mitcham's Fourth: a case for foregrounding volition when framing Design and Technology Education <i>Steve Keirl</i> <i>Goldsmiths, University of London, London, UK</i>	59
Using linkography to explore novice designers' design choices during a STEM task <i>Nicolaas Blom</i> <i>University of Pretoria, Pretoria, South Africa</i> <i>Grietjie Haupt</i> <i>University of Pretoria, Pretoria, South Africa</i> <i>Alfred Bogaers</i> <i>CSIR, Pretoria, South Africa</i>	65
Conceptualisation Processes and Making <i>Antti Pirhonen</i> <i>University of Tampere, Tampere, Finland</i>	71
The Delft Research Programme on Design for Concept Learning <i>Marc J. de Vries</i> <i>Delft University of Technology, Delft, The Netherlands</i>	76

Kindergarten Programming goes Mobile	81
<i>Asi Kuperman</i>	
<i>Tel Aviv University, Tel Aviv, Israel</i>	
<i>Ruti Aladjem</i>	
<i>Tel Aviv University, Tel Aviv, Israel</i>	
<i>Davis Mioduser</i>	
<i>Tel Aviv University, Tel Aviv, Israel</i>	
Learning Science and Technology from Play in Early Childhood Education	88
<i>Hanno van Keulen</i>	
<i>Windesheim Flevoland University of Applied Science, Almere, The Netherlands</i>	
<i>Mariska Venema</i>	
<i>Windesheim Flevoland University of Applied Science, Almere, The Netherlands</i>	
STEM in Northern Ireland Primary Schools: Where is it at, and where should it go?	96
<i>Dr Kieran McGeown</i>	
<i>St Mary's University College, Belfast, Northern Ireland</i>	
<i>Dr Michael Ievers</i>	
<i>Stranmillis University College, Belfast, Northern Ireland</i>	
STEM Associational Fluency: The Cross-Training of Elementary and Middle Grade Math, Science, and Engineering Pre-Service Teachers	103
<i>Elizabeth Deuermeyer</i>	
<i>Texas A&amp;M University, Texas, USA</i>	
<i>Michael De Miranda</i>	
<i>Texas A&amp;M University, Texas, USA</i>	
Innovating a Professional Technology Teaching Programme Based on Student Teachers' Expectations and Experience of Work-integrated Learning	116
<i>Werner Engelbrecht</i>	
<i>University of Johannesburg, Auckland Park, South Africa</i>	
Considerations for developing Integrated-STEM Courses at the Senior Secondary School Level in New Zealand	123
<i>Bruce Granshaw</i>	
<i>Victoria University, Wellington, New Zealand</i>	
<i>Emeritus Professor Cedric Hall</i>	
<i>Victoria University, Wellington, New Zealand</i>	
From High to Low Voltage: A genre approach for teaching to write about designing	132
<i>Gerald van Dijk</i>	
<i>Utrecht University of Applied Sciences, Utrecht, The Netherlands</i>	
<i>Sacha Toppel</i>	
<i>Utrecht University of Applied Sciences, Utrecht, The Netherlands</i>	
<i>Maaïke Hajer</i>	
<i>Utrecht University of Applied Sciences, Utrecht, The Netherlands</i>	
<i>Malmö University, Malmö, Sweden</i>	
Making it Work: A Case Study of Canadian Intermediate Technology Educators' Pedagogical Classroom Practice	140
<i>David D. Gill</i>	
<i>Memorial University of Newfoundland, Newfoundland and Labrador, Canada</i>	
Supporting Discourse using Technology-Mediated Communication: The Community of Inquiry in Design and Technology Education	148
<i>Adrian O'Connor</i>	
<i>Portmarnock Community School, Dublin, Ireland</i>	
<i>Niall Seery</i>	
<i>Athlone Institute of Technology, Westmeath, Ireland</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Donal Canty</i>	
<i>University of Limerick, Limerick, Ireland</i>	

Innovating an Initial Professional Education of Technology Teachers (IPETT) Programme <b>Rina Grobler</b> <i>University of Johannesburg, Johannesburg, South Africa</i>	156
Developing Technology Student Teachers' Volition through Curriculum-related Excursions <b>Francois van As</b> <i>University of Johannesburg, Johannesburg, South Africa</i>	167
Making Industrial Internships Effective for the Professional Development of Aspiring Science Teachers <b>Mandy Stoop and Rutger van de Sande</b> <i>Fontys University of Applied Sciences, Eindhoven, Netherlands</i>	175
Constructs of Quality and the Power of Holism <b>Richard Kimbell</b> <i>Goldsmiths, University of London, London, UK</i>	181
Exploring the Potential for Identifying Student Competencies in Design Education through Adaptive Comparative Judgment <b>Scott Bartholomew</b> <i>Purdue University, Indiana, USA</i> <b>Emily Yoshikawa</b> <i>Purdue University, Indiana, USA</i> <b>Pat Connolly</b> <i>Purdue University, Indiana, USA</i>	187
Implications of the Learning Sciences for the Unique Intent and Remit of Technology Education <b>Joseph Phelan</b> <i>University of Limerick, Limerick, Ireland</i> <b>Niall Seery</b> <i>Athlone Institute of Technology, Westmeath, Ireland</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i> <b>Donal Canty</b> <i>University of Limerick, Limerick, Ireland</i>	195
Speculative Writing: Enabling Design Thinking <b>Belinda von Mengersen</b> <i>National School of Arts, Australian Catholic University, Australia</i>	201
Developing Creativity and Imagination in Native Hawaiian Adolescents <b>Toni Marie Mapuana Kauli, Kamalani Doria, Kainalu Gomera, Samuel M. Kamakau IV, and Quinn Waiki</b> <i>Ka Umeke Kaeo Hawaiian Immersion Public Charter School, Hilo, Hawaii</i>	207
Connecting Authentic Innovation Activities to the Design Process <b>Joachim Svärd</b> <i>Dept. Social and Welfare Studies, Linköping University, Norrköping, Sweden</i> <b>Konrad Schönborn</b> <i>Dept. Science and Technology, Linköping University, Norrköping, Sweden</i> <b>Jonas Hallström</b> <i>Dept. Social and Welfare Studies, Linköping University, Norrköping, Sweden</i>	216
Cultural and historical roots for design and technology education: why technology makes us human <b>Matt McLain,</b> <i>Liverpool John Moores University, Liverpool, UK</i> <b>Dawne Bell,</b> <i>Edge Hill University, Ormskirk, UK</i> <b>David Wooff,</b> <i>Edge Hill University, Ormskirk, UK</i> <b>David Morrison-Love,</b> <i>University of Glasgow, Glasgow, UK</i>	223



Girls' Engagement in Technology Education: A Systematic Review of the Literature	231
<i>Ulrika N Sultan</i>	
<i>Linköpings University, Linköping, Sweden</i>	
<i>Cecilia Axell</i>	
<i>Linköpings University, Linköping, Sweden</i>	
<i>Jonas Hallström</i>	
<i>Linköpings University, Linköping, Sweden</i>	
Teacher Students' Critical Thinking Skills Using the Concept of Disruptive Technologies	239
<i>Cecilia Axell and Lars Björklund</i>	
<i>Linköping University, Norrköping, Sweden</i>	
Investigating T/E Design Based Learning: Student Ability to Select and Utilize STEM Content and Practices	246
<i>Susheela Shanta</i>	
<i>Center for Engineering, Governor's STEM Academy, Roanoke County Public Schools</i>	
<i>Roanoke, USA</i>	
<i>John G. Wells</i>	
<i>Virginia Tech, Blacksburg, USA</i>	
On Intelligence in Technology Education: Towards Redefining Technological Capability	256
<i>Jeffrey Buckley</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Niall Seery</i>	
<i>Athlone Institute of Technology, Westmeath, Ireland</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Donal Canty</i>	
<i>University of Limerick, Limerick, Ireland</i>	
<i>Lena Gumaelius</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
Investigating the Relationships between Spatial Ability, Interest, and Task Experience on Knowledge Retention in Engineering Education	263
<i>Tomás Hyland</i>	
<i>University of Limerick, Limerick, Ireland</i>	
<i>Jeffrey Buckley</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Niall Seery</i>	
<i>Athlone Institute of Technology, Westmeath, Ireland</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Jason R. Power</i>	
<i>University of Limerick, Limerick, Ireland</i>	
<i>Seamus Gordon</i>	
<i>University of Limerick, Limerick, Ireland</i>	
Supporting Learning Design Language in Primary Education	270
<i>Miroslava Silva Ordaz</i>	
<i>Delft University of Technology, Delft, The Netherlands</i>	
<i>Autonomous University of Queretaro, Santiago de Querétaro, México</i>	
<i>Remke Klapwijk</i>	
<i>Delft University of Technology, Delft, The Netherlands</i>	
<i>Gerald van Dijk</i>	
<i>Hogeschool Utrecht, Utrecht, The Netherlands</i>	

Attention and Action during the Design and Technology Lesson: by fine-tuning task characteristics	278
<i>Annemarie Looijenga</i> <i>Delft University of Technology, Delft, The Netherlands</i>	
<i>Remke Klapwijk</i> <i>Delft University of Technology, Delft, The Netherlands</i>	
<i>Marc de Vries</i> <i>Delft University of Technology, Delft, The Netherlands</i>	
Interdisciplinary Teaching in Swedish Primary Schools: Teachers' Perspectives of Subject-Matter Integration in Technology and History	288
<i>Catherine Couturier and Lars Geschwind</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Eva Hartell</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i> <i>Haninge Kommun, Stockholm, Sweden</i>	
A Preliminary Model of Problem Categorisation to Explore the Cognitive Abilities Required for Problem Solving in Engineering Education	295
<i>Clodagh Reid and Rónán Dunbar</i> <i>Athlone Institute of Technology, Westmeath, Ireland</i>	
<i>Jeffrey Buckley</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
Pupils' Goal Orientations in a Pedagogical Innovation Process: A Competition to Design and Manufacture Quick Hydrocopters	302
<i>Eila Lindfors</i> <i>University of Turku, Turku, Finland</i>	
<i>Vilma Heinola</i> <i>Compulsory school, Kauhajoki, Finland</i>	
<i>Suvi Kolha</i> <i>Pääskylvuori School, Turku, Finland</i>	
Developing a Learning Environment for Innovation Learning in Craft, Design and Technology Education	309
<i>Juha Jaatinen and Eila Lindfors</i> <i>University of Turku, Turku, Finland</i>	
Teachers' Views on Training Spatial Skills and Creative Thinking by Using Model Construction: A Case Study from South Korea and Sweden	319
<i>Lena Gumaelius</i> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Mariana Black</i> <i>National Museum of Science and Technology, Stockholm, Sweden</i>	
<i>Tom Callen</i> <i>Nordic4DFrame AB, Stockholm, Sweden</i>	
Spatial Ability and Approaches to Solving Word Problems in Mathematics	327
<i>Gavin Duffy</i> <i>Dublin Institute of Technology, Dublin, Ireland</i>	
<i>Brian Bowe</i> <i>Dublin Institute of Technology, Dublin, Ireland</i>	
<i>Sheryl Sorby</i> <i>University of Cincinnati, Cincinnati, USA</i>	
A National Spatial Skills Research & Development Project	333
<i>Brian Bowe</i> <i>Dublin Institute of Technology, Dublin, Ireland</i>	
<i>Rachel Harding</i> <i>Dublin Institute of Technology, Dublin, Ireland</i>	
<i>Theresa Hedderman</i> <i>Dublin Institute of Technology, Dublin, Ireland</i>	

<b>Sheryl Sorby</b> <i>University of Cincinnati, Cincinnati, USA</i>	
Maker education in the English context	341
<b>David Barlex</b> <i>University of Exeter, Exeter, UK</i>	
<b>Torben Steeg</b> <i>University of Exeter, Exeter, UK</i>	
Better making or making better: Exploring the attitudes of a school community to introducing a forge and blacksmithing into their school	347
<b>Tony Lawler and Kim Olliff</b> <i>King Alfred's School, London, UK</i>	
<b>Kay Stables</b> <i>Goldsmiths, University of London, London, UK</i>	
<b>Dominic Callaghan and Ralph Harris</b> <i>King Alfred's School, London, UK</i>	
Learning to weld in technical vocational education: the first cycle of an action-oriented study	356
<b>Nina Kilbrink</b> <i>Karlstad University, Karlstad, Sweden</i>	
<b>Stig-Börje Asplund</b> <i>Karlstad University, Karlstad, Sweden</i>	
Reconceptualising PCK Research in D&T Education: Proposing a Methodological Framework	363
<b>Andrew Doyle</b> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<b>Niall Seery</b> <i>Athlone Institute of Technology, Westmeath, Ireland</i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<b>Lena Gumaelius</b> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<b>Donal Canty</b> <i>University of Limerick, Limerick, Ireland</i>	
<b>Eva Hartell</b> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
Investigating the Potential for RGT and ACJ towards deeper insights of Teacher Assessment Practices	371
<b>Eva Hartell</b> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i>Haninge Kommun, Stockholm, Sweden</i>	
<b>Helena Isaksson Persson</b> <i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<b>Scott Bartholomew</b> <i>Purdue University, Indiana, USA</i>	
<b>Greg Strimel</b> <i>Purdue University, Indiana, USA</i>	
Addressing the issue of bias in the measurement of reliability in the method of Adaptive Comparative Judgment	378
<b>Camila Rangel-Smith</b> <i>Digital Assess at VTCT, London, UK</i>	
<b>Declan Lynch</b> <i>Digital Assess at VTCT, London, UK</i>	
Pre-service Teachers' Subject Knowledge in Secondary Design and Technology: Findings from an Empirical Study	388
<b>Mike Martin</b> <i>Liverpool John Moores University, Liverpool, England</i>	

Establishing Progressions of Learning in Engineering for High School Students	394
<i><b>Greg J. Strimel</b></i>	
<i>Purdue University, Indiana, USA</i>	
<i><b>Michael E. Grubbs</b></i>	
<i>Baltimore County Public Schools, Maryland, USA</i>	
<i><b>Tanner J. Huffman</b></i>	
<i>The College of New Jersey, New Jersey, USA</i>	
<i><b>Scott Bartholomew</b></i>	
<i>Purdue University, Indiana, USA</i>	
Professional Development Program for Teaching Engineering-Focused Curricula in Technology Education	400
<i><b>Kuang-Chao Yu</b></i>	
<i>National Taiwan Normal University, Taipei, Taiwan</i>	
<i><b>Szu-Chun Fan</b></i>	
<i>National Kaohsiung Normal University, Kaohsiung, Taiwan</i>	
<i><b>Kuen-Yi Lin</b></i>	
<i>National Taiwan Normal University, Taipei, Taiwan</i>	
Applying Project Based Learning to Teaching Robotics in Junior-high Schools	411
<i><b>Yair Zadok</b></i>	
Toward an Understanding of Dysgraphia as a Barrier to STEM-Related Careers	417
<i><b>Daniel P. Kelly</b></i>	
<i>Texas Tech University, Texas, USA</i>	
<i><b>Deidre L. Kelly</b></i>	
<i>North Carolina State University, North Carolina, USA</i>	
Using a problem solving toolkit – in an international distance learning course	423
<i><b>Osnat Dagan</b></i>	
<i>Beit Berl College, Beit Berl, Israel</i>	
Design Values, Preferences, Similarities, and Differences across Three Global Regions	432
<i><b>Scott R. Bartholomew</b></i>	
<i>Purdue University, Indiana, USA</i>	
<i><b>Emily Yoshikawa</b></i>	
<i>Purdue University, Indiana, USA</i>	
<i><b>Eva Hartell</b></i>	
<i>KTH Royal Institute of Technology, Stockholm, Sweden</i>	
<i><b>Greg J. Strimel</b></i>	
<i>Purdue University, Indiana, USA</i>	
Implementing Digital Technology in the New Zealand Curriculum	441
<i><b>Wendy Fox-Turnbull</b></i>	
<i>Faculty of Education, University of Waikato, New Zealand</i>	
A Model for Food Literacy Education	453
<i><b>Wendy Slatter</b></i>	
<i>University of Auckland, Auckland, New Zealand</i>	
<i><b>Bev France</b></i>	
<i>University of Auckland, Auckland, New Zealand</i>	
Food Education in the School Curriculum: A Discussion of the Issues, Influences and Pressures on the Teaching of Food	461
<i><b>Marion Rutland</b></i>	
<i>University of Roehampton, London, UK</i>	
Project-based learning in technology education: implications of the digital era	468
<i><b>Moshe Barak</b></i>	
<i>Ben-Gurion University of the Negev, Be'er Sheva, Israel</i>	

Multiple Design Representations to Foster Idea Development	475
<i>Keelin Leahy</i>	
<i>University of Limerick, Limerick, Ireland</i>	
Teaching young people to respond to a contextual challenge through designing and making – a discussion of possible approaches	490
<i>David Barlex</i>	
<i>University of Exeter, Exeter, UK</i>	
<i>Torben Steeg</i>	
<i>University of Exeter, Exeter, UK</i>	
Drawings to depict or drawings to explain: A whole-school analysis of children’s drawings of bridges	498
<i>Louise Milne</i>	
<i>University of Waikato, Hamilton, New Zealand</i>	
Effects of Convergent and Divergent Feedback on Creative Thinking During Children’s Design Processes	506
<i>Alice Schut and Remke Klapwijk</i>	
<i>Dept. Science Education &amp; Communication, Delft University of Technology, Delft, Netherlands</i>	
<i>Mathieu Gielen</i>	
<i>Dept. Industrial Design, Delft University of Technology, Delft, Netherlands</i>	
Perceptions and reality: Analyzing student experiences in ranking self and peer work through Adaptive Comparative Judgment	513
<i>Scott R. Bartholomew</i>	
<i>Purdue University, Indiana, USA</i>	
<i>Emily Yoshikawa</i>	
<i>Purdue University, Indiana, USA</i>	
<i>Greg Strimel</i>	
<i>Purdue University, Indiana, USA</i>	
Teaching Sustainability in Technology Education: Perception Versus Practice	521
<i>Beineán Conway, Keelin Leahy and Muireann McMahon</i>	
<i>University of Limerick, Limerick, Ireland</i>	
Using Engineering Design Challenges to Promote Imagination and Innovation in Integrative STEM Education	535
<i>Edward M. Reeve</i>	
<i>Utah State University, Logan, Utah, USA</i>	
Scientific and Technological Processes in K-12 classrooms in Quebec Schools: Common Features and Differences	542
<i>Brahim El Fadil</i>	
<i>University of Sherbrooke, Quebec, Canada</i>	
<i>Abdelkrim Hasni</i>	
<i>University of Sherbrooke, Quebec, Canada</i>	
<i>Joël Lebeaume</i>	
<i>University of Paris-Descartes, Paris, France</i>	
Outline of workshops	551
Conference schedule	553

# Rethinking Pupils' Attitudes Towards Technology (PATT) studies

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Pupils' Attitudes Towards Technology (PATT) studies and the PATT Foundation have played an international leadership role in the field of technology education for just over three decades. It has been instrumental in determining the research agenda and establishing an international research fraternity in technology education (Jones et al. 2013; Mottier et al. 1991). However, the number of classical PATT studies focusing on students' views of technology at PATT conferences has declined (Volk and Yip 1999; Williams 2013; 2016). Recent PATT studies conducted during the past five years included the PATT Short Questionnaire (PATT-SQ) (Ardies et al. 2013), as well as its translated Swedish version labelled PATT-SQ-SE (Svenningsson et al. 2016), the PATT-ELEM instrument for elementary school students (Holter 2016), and the PATT-STEM instrument for measuring upper secondary school students' attitudes towards and concepts of engineering as part of Science, Technology, Engineering and Mathematics (STEM) education (Kőycü and De Vries 2016). The purpose of the paper is to establish innovative and imaginative ways to fundamentally rethink and revitalise PATT studies. The following research question underpinned the study: Which components of students' attitudes towards technology should be innovatively and imaginatively researched further? A meta-analysis of the so-called mainstream PATT-instruments (Ankiewicz 2018a) as well as new, non-related instruments (Ankiewicz 2018b) indicated that these mainly measure the cognitive and affective components of students' attitudes and not the behavioural component. Except for the Human Being and Technology (HBT) questionnaire (Järvinen and Rasinen 2015) the closest that other instruments came to ascertaining the behavioural component (activities) was to measure readiness for action (e.g. the Attitudinal Technology Profile (ATP) questionnaire) (Ankiewicz et al. 2001). The findings suggest that future PATT studies which include a focus on innovative and imaginative ways to ascertain the behavioural component of attitudes could make an important contribution to the existing body of knowledge.

*Key words: PATT studies, Attitudes, Attitude measurement, Behavioural component*

## 1. INTRODUCTION

### ***1.1. The contribution of the Pupils' Attitudes Towards Technology (PATT) Foundation and its studies to instruments for ascertaining students' attitudes***

Before the 1980s, research related to students' attitudes towards technology was unusual (Yu et al. 2012). In the 1980s, several countries introduced technology education as a successor to some form of craft or technical education and it began to develop its own distinct research area. Studies into students' attitudes towards and concepts of technology mostly contained information on students' ideas when entering technology education (Kőycü and De Vries 2016).

The most noted study of students' attitudes towards technology has probably been the work pioneered by Prof. Jan Raat and Marc de Vries as part of "Project Physics and Technology" in the Department of Physics Education at Eindhoven University of Technology in the Netherlands in 1984 (De Vries 1988; Volk and Yip 1999). The first part of the research was done among students of ages 13 to 14 in secondary general education regarding their attitudes as well as how they conceptualised technology.

The PATT instrument used in the Netherlands, referred to as PATT-NL, was the first instrument specifically designed for this purpose. Results in the Netherlands were so significant that an international extension of the research was the logical next step (Ardies et al. 2013). In 1986, ten countries participated in pilot studies with the aim to increase the reliability and validity of the PATT-NL instrument. In 1987, 12 countries from across

the world (e.g. Australia, India, Kenya, Mexico, Nigeria and also European countries like Belgium, France, Italy, Poland and the UK) started using PATT-NL in survey studies with the aim to ascertain and describe the attitudes of students towards technology (De Klerk Wolters 1989a, 1989b; Dugger 1988).

Initially PATT studies aimed to investigate secondary school students' attitudes and the concepts they had of technology (De Klerk Wolters 1988). PATT studies were a means of generating theoretical knowledge with practical implications for the development and assessment of technology education and was not aimed primarily at curriculum content (De Klerk Wolters 1989a), although it valued the link between research and curriculum development (Raat 1988).

The subsequent development of related international surveys led to workshops and the annual PATT conference, which has brought scholars involved in technology education together for over 25 years to provide a discussion platform for PATT-related issues (Jones et al. 2013; Kőycú and De Vries 2016; Volk and Yip 1999). PATT studies as well as the PATT Foundation have played an international leadership role in the field of technology education. It has been instrumental in determining the research agenda and establishing an international research fraternity in technology education. It has also become an international discussion forum for all aspects of technology education, like curriculum development, research, teacher education, assessment and pedagogical issues in primary and secondary schools. It brings scholars together to offer opportunities for an exchange of ideas and information to contribute towards the development of technology education (Jones et al. 2013; Mottier et al. 1991).

## ***1.2. Problem statement***

PATT conferences, because of their frequency, are the most productive source of research papers in the field of technology education (Williams 2016). The number and ranking of classical PATT studies focusing on students' views of technology at these conferences have however declined over time in favour of technological literacy, which is still the most common category of papers presented (Volk and Yip 1999; Williams 2013, 2016). Hence, it may seem as if research questions concerning the PATT survey in its current form have been exhausted and that there is a need to fundamentally rethink and revitalise PATT studies. In my view the decline in the use of the PATT survey in contemporary research may be ascribed to the maturation of technology education over the past three decades (De Vries 2018). Initially there was a substantial number of pilot and survey studies using the mainstream PATT instruments in countries around the world to ascertain students' ideas when entering technology education (Kőycú and De Vries 2016). The general research findings regarding students' attitudes towards and concepts of technology, in particular in the PATT studies (Ankiewicz 2018a) have provided researchers with a good understanding of students' ideas when entering technology education.

Recent PATT studies conducted during the past five years included the PATT Short Questionnaire (PATT-SQ) (Ardies et al. 2013), as well as its translated Swedish version labelled PATT-SQ-SE (Svenningsson et al. 2016); the PATT-ELEM instrument for elementary school students (Holter 2016), and the PATT-STEM instrument for measuring upper secondary school students' attitudes towards and concepts of engineering as part of Science, Technology, Engineering and Mathematics (STEM) education (Kőycú and De Vries 2016). These recent studies do not seem fundamentally different from the initial mainstream PATT studies. These differed in pragmatic and contextual aspects such as length, research methodology, age, terminology and were done in the related field of engineering. The issue of length with PATT-NL and PATT-USA (Ardies et al. 2013; Volk and Yip 1999) was addressed by the shorter PATT-SQ version (Ankiewicz, 2018a). The purpose of PATT-SQ-SE was to increase knowledge about student interpretations and the meaning of their answers. A qualitative dimension was added to the recently developed PATT-SQ to explain and interpret the quantitative data (Svenningsson et al. 2016). PATT-ELEM is an adapted version of PATT-USA for elementary school students, by updating the technological terminology (Ankiewicz 2018b). PATT-STEM resulted from the adaptation of PATT-USA for measuring upper secondary school students' attitudes towards and concepts of engineering as part of STEM education (Ankiewicz 2018b). In order to better understand what has been measured by the various instruments it is necessary to analyse the concept of "attitudes".

### ***1.3. The traditional approach to attitudes***

Attitude is a broad concept with different definitions and interpretations. A controversy has long existed in literature regarding the dimensionality of attitudes, with various models comprising one to three dimensions (Ankiewicz et al. 2001; Ardies et al. 2013). The traditional approach is that attitudes have an integrated three-dimensional nature, consisting of cognitive, affective and behavioural components (Breckler 1984; Fishbein and Ajzen 1973; Ostrom 1969). This approach forms part of the consistent theories as one category of three attitude theories, namely functional, formational and consistent theories. Attitude theories and their components are not exclusive but complement one another (Metsärinne and Kallio 2015). Formational (Bloom's taxonomies of educational objectives/learning domains i.e., knowledge, skills and attitudes) and consistent theories of attitudes (i.e., cognitive, affective and behavioural components) as well as Mitcham's philosophical framework can be related to one another to some extent (Ankiewicz 2018c).

The cognitive component of attitudes includes a person's ideas or opinions that express the relationship between situational and attitudinal objects (Gagné 1977). Statements that reflect a person's perception and knowledge of the attitudinal object are part of the cognitive component (Corsini and Ozaki 1984). The affective component refers to a person's "feeling" or emotion concerning an attitudinal object (Heaven 1982). The behavioural component includes a person's predisposition or readiness for action, as well as his or her actions concerning the "behavioural object" (Ankiewicz et al. 2001; Gagné 1977). For Bagozzi and Burnkrant (1979) attitude is primarily the interplay of affect and cognition, with the behavioural tendency as a secondary consequence (Ankiewicz et al. 2001; Van Rensburg et al. 1999).

According to the traditional approach, an attitude towards a concept such as technology thus is the person's collection of beliefs about it (cognitive component) and associated episodes linked with emotional reactions (affective component). The stimulation of these reactions results in decisions to engage in behaviour (behavioural component), such as choosing to take a technology course, to read about technological matters or to adopt a technology-related hobby (Ankiewicz et al. 2001; White 1988). Researchers in technology education often acknowledge, either implicitly or explicitly, the traditional approach to attitudes (De Klerk Wolters 1988; 1989a; Metsärinne and Kallio 2015; Rohaan et al. 2010; Tseng et al. 2013; Volk and Yip 1999). A possible means to fundamentally rethink and revitalise PATT studies is to identify which of the components of the traditional approach to attitudes have been measured by the various instruments and then to focus on those components which may have received less or no attention.

### ***1.4. Purpose, research question and research methodology***

The purpose of the paper is to establish innovative and imaginative ways to fundamentally rethink and revitalise PATT studies. The following research question underpinned the study: Which components of students' attitudes towards technology should be innovatively and imaginatively researched further? In order to answer the research question, one should first identify which of the components of the traditional approach to attitudes are being measured by the various instruments. The research methodology for this position paper consisted of a meta-analysis of the literature regarding the components of attitudes in technology education measured by various attitude instruments. The components of attitudes that are measured by the mainstream PATT instruments, namely PATT-NL, PATT-USA and PATT-SQ will be identified in the next section.

## **2. THE MAINSTREAM PATT INSTRUMENTS**

De Klerk Wolters (1988:41), who was involved in the design of PATT-NL, described attitudes as "a certain negative or positive feeling towards technology based on certain knowledge of and ideas about technology that may lead to a certain behaviour with reference to technology". In this context, attitude was used as a collective term for someone's affinity, behaviour and conceptualization in relation to technology (Rohaan et al. 2010), in accordance with the traditional approach and consistent theories of attitudes (Ankiewicz 2018b; De Klerk Wolters 1989a).

PATT-NL consisted of two questionnaires, measuring the affective component and the cognitive component. The attitude questionnaire with six subscales measuring affective components of attitude such as interest,



gender, consequences, difficulty, curriculum and careers in technology (Ankiewicz 2018b; De Klerk Wolters 1988; Rennie and Jarvis 1995; Rohaan et al. 2010; Van Rensburg et al. 1999).

One of the aims of technology education is the development of a positive concept of technology; therefore, students' concepts have always been an important element in PATT studies (De Vries 2005). The concept questionnaire with four subscales measuring the cognitive or knowledge component of attitude towards technology, based on the five general characteristics of technology. (Ankiewicz 2018b; Bame and Dugger 1989; Becker and Maunsaiyat 2002; De Klerk Wolters 1989a, 1989c; De Vries 1992; Jeffrey 1993; Rennie and Jarvis 1995; Rohaan et al. 2010; Van Rensburg et al. 1999).

In its early form, PATT-NL included an essay (qualitative) section (Luckay and Collier-Reed 2014). This read: Technology can mean different things to different people. When you read the word "technology" what comes into your mind? to ascertain students' cognitive views of technology (Ankiewicz 2018a, 2018b).

De Klerk Wolters (1989a) mentioned only with the PATT-NL version for younger students that the attitude questionnaire also measured the behavioural component. Earlier he had stated pertinently that the original PATT-NL did not measure the behavioural component (De Klerk Wolters 1988). I am of the opinion that this might have been an oversight. The questionnaire can only measure students' readiness for action, and not the action itself.

The original PATT-NL was translated and modified by Bame et al. (1993) for use in the USA (Ankiewicz 2018a, 2018b; Volk and Yip 1999). PATT-USA was a one-page instrument consisting of four parts. The first was a short, written description of technology; then 11 questions to gather demographic data and information about the technological climate of students' homes; 58 statements (items 12-69) to assess students' attitudes towards technology (affective component); and 31 statements (items 70-100) to assess students' concept of technology (cognitive component). The PATT-NL essay question was replaced with a brief statement of what the students thought technology was (Ankiewicz 2018a; Bame and Dugger 1989; Boser et al. 1998; De Klerk Wolters 1988, 1989a).

The attitude questionnaire (affective component) of the PATT-USA instrument as developed in the 1990s was recently reconstructed and revalidated by Ardies et al. (2013) (Ankiewicz 2018a, 2018b). This resulted in the shorter PATT-SQ instrument with six sub-factors (career aspirations, interest in technology, tediousness, positive perception of effects of technology, perception of difficulty, and perception of technology as a subject for boys or for boys and girls) and 24 items of attitude towards technology (Ardies et al. 2013).

PATT-NL and PATT-USA, in accordance with the traditional approach to attitudes, only ascertained students' technological concepts (cognitive component) and attitudes (affective component) as crucial prerequisites for technological activities (behavioural component) (Ankiewicz et al. 2001; De Klerk Wolters 1988; Van Rensburg et al. 1999). PATT-SQ, as well as its translated, Swedish version, labelled PATT-SQ-SE (Ankiewicz 2018b; Svenningsson et al. 2016), only ascertained students' attitudes (affective component). The three mainstream instruments did not address the behavioural component of attitude. The aspects of the traditional approach to attitudes that the new, non-related instruments to PATT studies, namely ATP and HBT measure, will be identified in the next section.

### **3. THE ATTITUDINAL TECHNOLOGY PROFILE (ATP) QUESTIONNAIRE AND THE HUMAN BEING AND TECHNOLOGY (HBT) QUESTIONNAIRE**

In order to resolve some of the contextual and formulation problems experienced with PATT-USA in South Africa, Van Rensburg et al. (1999) designed the Attitudinal Technology Profile (ATP) questionnaire to be used in the lower secondary school (ages 13 to 14). In Part A of this instrument, students were familiarised with the construct of technological product to avoid misconceptions. In Part B, 24 items were included on a five-point Likert-type scale to assess students' attitudinal technology profile (Ankiewicz 2018a, 2018b; Ankiewicz et al. 2001).

The items were designed and formulated as descriptive propositions linked to the affective components of the content of technology and attitude. By using descriptive propositions, it was also possible to integrate the affective component of attitude to some extent with the behavioural component (only students' readiness for action) (Ankiewicz 2018a; Ankiewicz et al. 2001; Van Rensburg et al. 1999).

The Human Being and Technology (HBT) questionnaire was devised to examine students' learning related to the HBT cross-curricular theme among grade 9 Finnish students. It was divided into three sections, namely questions on students' knowledge about technology (cognitive component), their attitudes towards technology (affective component) and their activity know-how (behavioural component). Students' knowledge was measured by 15 questions. These included "right" or "wrong" statements, multiple-choice questions (some with pictures) and open-ended questions. Issues related to attitudes towards technology were studied by means of 20 items which students assessed using a five-point Likert scale. Students' activity know-how was measured by 15 questions. These included 14 statements with a "yes" or "no" answer dealing with both modern technology and more traditional themes concerning manual skills, and a single open-ended assignment where students were asked to devise as many new uses for a clothes-peg as possible (Järvinen and Rasinen 2015). The HBT questionnaire appears to be the first instrument to include a section that measures students' actions or technological activities (thus behavioural component) directly as part of the behavioural component of attitudes, and not only students' readiness for action as with the various PATT mainstream instruments. This was an extension of the ATP questionnaire, which measured the readiness for action as part of the behavioural component (Ankiewicz 2018b; Ankiewicz et al. 2001). The new, non-related instruments to PATT studies, namely ATP and HBT thus also measured the behavioural component to some extent.

#### 4. CONCLUSION

It was found that the mainstream PATT-NL instrument and its derivatives (i.e., PATT-USA and PATT-SQ) were aligned with the traditional approach to attitudes with an integrated three-dimensional nature. It is noteworthy that specific instruments were designed to measure only particular components of students' attitudes (Refer to Table 1). The mainstream PATT instruments ascertained students' technological concepts (cognitive component) and attitudes (affective component) as crucial prerequisites for technological activities (behavioural component) (Ankiewicz et al. 2001; Van Rensburg et al. 1999). However, these instruments did not ascertain the behavioural component of students' attitudes. Except for the HBT questionnaire the closest that other instruments came to ascertaining the behavioural component was to measure readiness for action (e.g. the ATP questionnaire).

Table 1. The particular components of students' attitudes that specific instruments measure (indicated by an X)

<i>PATT mainstream instruments</i>	<i>The integrated three-dimensional nature of attitudes according to the traditional approach</i>		
	<i>Cognitive component</i>	<i>Affective component</i>	<i>Behavioural component</i>
<i>PATT-NL (attitude questionnaire; concept questionnaire; essay section)</i>	X	X	
<i>PATT-USA (attitude part; concept part; brief statement of what the students thought technology was)</i>	X	X	
<i>3. PATT-SQ (based on the attitude part of PATT-USA)</i>		X	
<i>New, non-related instruments to PATT studies</i>	<i>The integrated three-dimensional nature of attitudes according to the traditional approach</i>		
	<i>Cognitive component</i>	<i>Affective component</i>	<i>Behavioural component</i>
<i>1. Attitudinal Technology Profile (ATP) questionnaire</i>		X	X (Only students' readiness for action)

The overwhelming majority of instruments have been focusing on the cognitive and/or affective component of attitudes, neglecting the behavioural component. In order to fundamentally rethink and revitalise PATT studies, students' attitudes towards technology should perhaps in future be ascertained more innovatively, imaginatively and holistically by also focusing on the behavioural component as one of the three components of attitudes. The researchers involved in the recent HBT questionnaire have done some ground-breaking work in this regard.

PATT studies have provided some important insights into the relationship between two of the three traditional components of attitudes. A general finding from the PATT studies (Ankiewicz 2018a) was that students' concepts of technology were strongly related to their attitudes toward technology. Concept appears to influence affect and not the other way around (De Klerk Wolters 1989c; Rohaan et al. 2010). However, the relationship between them and behaviour is still unknown.

As a result of the behavioural component being neglected, its relationship with the other two components (knowledge and affective) remains unknown. Although the HBT questionnaire measured the behavioural component of students' attitudes, it did not seem to investigate the effect of this component on the other two components. Ultimately technology teachers do not only have to develop students' attitudes towards and concepts of technology but also their behaviour or activities. From a student-centred perspective they should also be able to "do" technology (Ankiewicz 2015). If the behavioural component of students' attitudes were to be ascertained in future, the results might lead to insights into the relationship between behaviour and knowledge as well as affect. This might better support more holistic teaching and learning practices in technology education in which the integrated three-dimensional nature of students' attitudes towards technology is emphasised.

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# Woman's under-representation in STEM: The part role-models have played in the past and do we still need them today?

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In 2005, Blickenstaff wrote that women were under-represented in science, technology, engineering and mathematics (STEM) in both education and careers in most industrialised countries around the world. This under-representation is not something new, it was identified as problematic as early as the 1980s (Kelly et al., 1981; Smail et al., 1982). While encouraging girls to study and pursue careers in the technology sector continues to be problematic even today (Bauer, 2017). After introducing the topic, the paper begins with a brief discussion of some of the factors that researchers have believed influenced this under-representation. Several ways forward to improve the state of affairs from the literature are then discussed, before turning to concentrate specifically on role-models and the part that they can play in changing the situation. The next section focuses on the author's personal experiences of being a role-model in a male-dominated workplace in the mid-1960s when she started her career as the first qualified female woodwork teacher in the UK having trained as a product designer and maker of furniture. This is followed by a discussion of various research projects concerned with the positive effects of role model exposure in terms of: motivating individuals through acting as behavioral models, representing the possible, being inspirational; improving a sense of belonging; impacting on academic self-efficacy; and negating stereotypes. The final section looks at very recent research and comes to some conclusions about the question posed in the paper's title: Do we still need role-models today?

*Key Words: Role-models, under-representation, STEM*

## 1. INTRODUCTION

The aim of this paper is first to analyse and discuss factors from relevant literature that have influenced women's continued under-representation in science, technology, engineering and mathematics (STEM) education and subsequent careers. This is followed by an analysis and discussion of role model literature concerning the positive and negative effects that exposure to role models has had, and the forms that such role models have taken in order to improve women's representation in STEM. The author's personal experiences of role models and being a role-model herself have been woven into the discussion. The final section sums up the findings and provides some conclusions concerning whether or not role models are still required today.

## 2. WOMEN'S UNDER-REPRESENTATION

In 2005, Blickenstaff wrote that women were under-represented in STEM, in education and careers in most industrialised countries around the world. This concern had been highlighted in 2002 by Baroness Greenfield (2009) in her Report on Women in Science, Engineering, and Technology.

The under-representation of women in science, engineering and technology threatens, above all, our global competitiveness. It is an issue for society, for organisations, for employers and for the individual. (Greenfield, 2002, p.9.)

This state of affairs has been debated by many others (e.g. Darmody & Smyth, 2005; Shin, Levy & London, 2016; Smith, 2011; van Aalderen-Smeets & Walma van der Molen, 2018) and remains an area of political priority and concern (Smith, 2011) in terms of education and the current and future job market (Noonan, & Laffarge, 2017) even today. This is a complex issue (van Aalderen-Smeets & Walma van der Molen, 2018). It is not something new (Atkinson, 1997). It was identified as problematic as early as the 1980s (Kelly Smail, & Whyte, 1981; Smail, Whyte, & Kelly, 1982), with unequal participation in STEM subjects remaining virtually unchanged for the past 35 years (Smith, 2011; Ceci, Williams & Barnett, 2009; Noonan & Laffarge, 2017).

This has been despite initiatives such as the introduction of comprehensive education, equal opportunity legislation and many interventions specifically targeted at encouraging female participation in various aspects of STEM. For example: TVEI – Technical and Vocational Education Initiative in 1982; WISE - Woman into Science and Engineering in 1984; GIST – Girls into Science and Technology in 1985 and jumping to more recent times, Girls in Tech in 2007, Technovation in 2010 and Little Miss Geek in 2012. Added to these has been the compulsory participation of all pupils in STEM subjects in primary and lower secondary level since the introduction of the National Curriculum (Atkinson, 1997) and a willingness by many STEM teachers to tackle the gender imbalance. However, shortages witnessed in girls’ take-up and their levels of success in STEM subjects during secondary education have continued to the present day (Bauer, 2017) even though girls have been shown to generally do better than boys in secondary education (Dury, Siy, & Cheryan, 2011). Also, there has been evidence of an understanding by many teachers of the fact that different students cope differently with the perceived challenges in STEM subjects (van Aalderen-Smeets & Walma van der Molen, 2018).

Reasons for increasing female participation in STEM such as ‘achieving a fair and just society’ and realising ‘public and private benefits’ (Smith, 2011 p.2) have been highlighted (e.g. Shin et al. 2016), with the need for a change in culture being portrayed as one way forward (Darmody & Smyth, 2005). References to large and small-scale interventions by parents, schools and teachers have been shown to influence and stimulate incremental beliefs about the malleability of females’ capacities when choosing whether to study STEM subjects (van Aalderen-Smeets & Walma van der Molen, 2018). However, Shin et al. (2016) supported Rosenthal, Levy, London, Lobel & Bazile’s (2013) belief that the impact of such interventions appeared to be short lived.

In terms of STEM career choices, Smith (2011) indicated that poor pay, a lack of career prospects and a failure to respond to the changing demands of an increasingly globalised STEM market were all persistent features responsible for female under-representation. Darmody & Smyth (2005, p.12) concurred stating that ‘occupational segregation’ found in advanced industrial societies remained a disappointing feature. This lack of females in STEM careers has also been exacerbated by low levels of recruitment into appropriate courses during tertiary education (Ceci et al., 2009; Dury et al., 2011; Shin et al., 2016; Smith 2011) and high levels of female dropout during pertinent degree courses (Shin et al., 2016; Smith, 2011; Sorby, 2009) even though in general at the age of 19 more women than men attend universities (Broecke and Hamed, 2008). Darmody & Smyth (2005, p.11) wrote about ‘preferences and expectations’ in terms of female STEM career choices at the end of secondary and tertiary education indicating the importance of family involvement, in particular a father’s attitude and aspirations for his daughter which they highlighted as being influential, alongside the importance of an educational establishment’s informal rather than formal sources of advice (Darmody & Smyth, 2005). Van Aalderen-Smeets & Walma van der Molen (2018) and others (e.g. Shin et al., 2016) indicated that career choices needed to be a careful matching process with the choice to study STEM being matched to the personal interests and aspirations of a student, if it was to be successful.

In 2005, Blickenstaff’s analysis of literature concerning the lack of women in STEM identified nine reasons for the phenomena, although he believed that some points in the list had not been adequately proven. The nine reasons with additional support from more recent research, were as follows:

1. Biological differences. Early research indicated biological differences while more recent research largely refuted the earlier findings suggesting to Blickenstaff that if differences still existed it would be dangerous to emphasise them, as that could signal that no action was required, as research indicated that biological differences could not be overcome. He and others (e.g. Darmody & Smyth, 2005; Dury et al., 2011) also suggested that at times the only way a female could ‘infiltrate’ the STEM world was to act like a ‘female male’;
2. Girls lack of academic preparation for a STEM career. This reason Blickenstaff believed was open to criticism as research had indicated that the opportunities for academic preparation were provided, it was just that they were rarely taken up. The other eight reasons in Blickenstaff’s list providing some explanations for this lack of up-take;
3. A lack of positive STEM attitudes and early experiences of STEM. An absence of positive attitudes was well supported by both early research (e.g. Weinburgh, 1995) and in more recent times (e.g. van

Aalderen-Smeets & Walma van der Molen, 2018). Although there remains strong disagreement over a dearth of positive early experiences of STEM being available (e.g. Roberts, 2016);

4. Irrelevant STEM curricula. Van Aalderen-Smeets & Walma van der Molen, (2018) added that girls found STEM lessons both difficult and boring;
5. Pedagogy in STEM teaching favouring males. This was reinforced by Dury et al. (2011) who considered STEM teaching to be masculine and incompatible with female needs and ways of learning; 'A chilly climate' in STEM classes (Blickenstaff. p.372). This was also referred to as an unsociable environment by Dury et al. (2011), Barbercheck (2001) and Gherasim, Butnaru & Mairean (2013);
6. An inherent masculine STEM epistemology. In terms of the nature of the knowledge required to be learnt, which Dury et al. (2011) referred to as, male teachers being preoccupied with male-orientated technologies;
7. Cultural pressure to conform to traditional gender roles. This was upheld by Shin et al. (2016) who agreed that cultural pressure could discourage females from pursuing and persisting in both STEM subject matter and careers;
8. An absence of female role models. This has been a recurring theme throughout the literature and one that is addressed in Section 3 of this paper.

In terms of gender differences in the ways that people learn highlighted in Blickenstaff's list above, various researchers worldwide have discussed possible causes (e.g. Feingold, 1994; Pomerantz, Altermatt, & Saxon, 2001). Gurian & Stevens, (2004) indicated a disconnect between teaching practice and the needs of male and female brains, while others have discussed the effect of various personality traits (e.g. Feingold, 1994; Ruble, Greulich, Pomerantz & Gochberg, 1993) and that such differences remain robust across cultures (Costa, Terracciano, & McCrae, 2001; Gurian & Stevens, 2004). Samuelsson & Samuelsson (2014) highlighted a plethora of internal and external contextual factors, while Gurian and Stevens (2004) discussed structural and functional brain differences that many believed profoundly affected human learning while they agreed with others that recognising such differences could lead to the identification of solutions to the many challenges experienced in the classroom.

Smith (2011) suggested that in terms of STEM learning the root of the problem lay in poor quality STEM education which she and others (Fraser, 2014; Sorby, 2009) believed was partially caused by inadequate training of STEM teachers. This she indicated led to negative attitudes towards STEM by primary school teachers who lacked specific STEM skills, which then caused students problems when choices had to be made during secondary education. At tertiary level Sorby (2009) reported specifically on a lack of cognitive skills required for engineering. She signposted, for example, robust gender differences in 3-D rotation abilities that favoured males, although her research overturned what she considered a false belief that one was either 'born with or not' (p.478) such skills as her research indicated that these skills could be improved through practice with a greater positive impact on female rather than male students.

Many authors referred to the importance of psychological factors when considering the reason for female under-representation in STEM. Van Aalderen-Smeets & Walma van der Molen (2018) stressed that malleability of intelligence was an important factor. They suggested that those holding entity theories of intelligence were more susceptible to internalising gender stereotypical beliefs which then negatively impacted upon school subject optional choices and therefore career choices, while those holding incremental beliefs were affected less as they believed they could overcome gender disadvantages with hard work.

Other authors referred to further psychological factors that could negatively affect females' attitudes towards STEM. Factors such as: expectancy in terms of goals and motivation (Morgenroth, Ryan & Peters, 2015); the impact of natural aptitude and ability that were self-perpetuating if left unchallenged (Darmody & Smyth, 2005); a lack of interest and negative attitudes (van Aalderen-Smeets & Walma van der Molen, 2018); self-doubt (Fraser, 2014) and closely related, a lack of confidence (Cameron & Hayde, 2014) and self-efficacy (van Aalderen-Smeets & Walma van der Molen, 2018); a lack of 'belongingness' and insecurity (Morgenroth et al., 2015; Shin et al., 2016).

Also, signposted as significant has been the negative effect of stereotyping. Darmody & Smyth (2005) referred to female self-stereotyping, while the issue of 'stereotype threat' that has been shown to affect many females in



a STEM context (Bages, Verniers, Martinot, 2016; Ceci et al., 2009; Collins, 2009; Dury et al., 2011; Morgenroth et al., 2015; Stroessner & Good, nd.; Wright, 2018). Shin et al. (2016) and van Aalderen-Smeets & Walma van der Molen (2018) indicated that stereotypical beliefs were stronger in females than males and were exacerbated by social class (Darmody & Smyth, 2005). Shin et al. (2016) referred to ‘cultural stereotyping’ illustrating this with an example from their data, indicating that only gifted, European/US white males were successful in STEM, while Darmody & Smyth (2005) referred to rural, conservative, schools where stereotypical beliefs were more entrenched than in town and city schools. A longer discussion of these important issues causing the under-representation of females in STEM is beyond the scope of this paper although many of the factors already mentioned, impinge upon the effectiveness of role models and are discussed in the next section of this paper.

### 3. ROLE MODELS

Role models mean different things to different people (Casserly, 2010). Morgenroth et al., (2015) suggested that role models had three distinct functions as: a behavioural model; a representation of the possible; an inspiration. There have also been those who believed that their function was as a mentor (Collins, 2009; Cameron, 2014; Fraser, 2014). However, all writers have signalled their agreement concerning the usefulness of role models in regards of motivating others, and pertinent to this paper, their efficacy in encouraging females in under-represented situations to believe that their goals were achievable (Cameron & Hayde, 2014; Drury et al., 2011; Fraser, 2014; Shin et al., 2016).

The importance in terms of what a role model represents has been shown to be key. Successful role models tend to come from domains or groups to which the aspirant belongs (Lockwood & Kunda, 1997). These include groups such as: family networks; those in the same educational or work environments; those in similar socio-cultural situations (Ceci et al., 2009; Darmody & Smyth, 2005; Morgenroth et al., 2015). In my case the two role models that inspired me were from my educational environments. They were a female art and craft teacher during my schooldays and a male lecturer from when I was a student studying furniture design. These teacher role models were both excellent craftsmen and I was inspired by their ability and encouraged to develop not only craft skills but also a thirst for new knowledge, an appreciation of working with materials and a need for accuracy in all that I did, while still allowing me space to grow, make my own mistakes and be creative and innovative. They helped me believe that I could meet all challenges head-on and that through hard work I could achieve whatever goals I set myself. Their example encouraged me to try to achieve excellence in all that I did. My family network was extremely supportive of my ambitions and proud of my successes. They even bought me my own Meccano set. However, neither of my parents could act as a practical STEM role model, as their careers were far removed from STEM, although interestingly enough my much younger brother went on to become a civil engineer.

The literature concerned with highlighting attributes of successful role models has supported my understanding of pertinent characteristics. Authors have variously described role models as needing to be: motivating (Casserly, 2010; Cameron, 2014, Morgenroth et al., 2015); attainable, otherwise the aspirant may feel demoralised or incompetent in comparison to a ‘superstar’ (Bages et al, 2015; Lockwood & Kunda, 1997; Shin et al., 2016); relevant, indicating that if not relevant by not being in the same field, then the person being inspired would just be ‘proud’ to be associated with the superstar without that positively affecting their motivation to succeed in their own field (Bages et al., 2015; Lockwood & Kunda, 1997; Morgenroth et al., 2015); inspirational, in terms of being inspired by, or inspired to (Cameron, 2014; Fraser, 2014; Lockwood & Kunda, 1997; Morgenroth et al., 2015); desirable, suggesting that the aspirant had a shared sense of ‘group membership’ (Morgenroth et al., 2015) and therefore a sense of ‘belonging’ (Rosenthal et al., 2013, p.470); compatible, so that the aspirant was able to contradict the stereotype of gender incompatibility (Rosenthal et al., 2013); similar in social standing, which researchers have linked to interests and values (Ceci et al., 2009; Lockwood & Kunda, 1997; Morgenroth et al., 2015); confident in themselves and their ability to achieve their ambition (Fraser, 2014). It has also been shown to be important that a role model’s success could be explained by effort rather than innate ability or talent (Bages et al, 2015). In terms of being a role model myself, I hope that throughout my career I have been seen to possess some of these positive characteristics, with my passion for all things STEM related and my ambition to pass on that passion to others being a visible aspect of my persona.

Research has indicated that it is not just the type of role model that is important in the relationship. A role model is only likely to inspire if the aspirant already has a well ignited spark of interest in the role model's field of expertise. The aspirant's own characteristics are also important. If Aspirants believe that their intelligence and ability are stable, controllable and malleable then they will believe that the success achieved by a role model is attainable (Morgenroth et al., 2015). In contrast, if an aspirant believes that intelligence is fixed and unchangeable then they will believe that the role model's success is not achievable (Bages et al. 2015). They must also believe in self-enhancement, having trust in their own capabilities (Lockwood & Kunda, 1997) and that even if the goal is not achievable immediately, that there is a possibility of attaining success in the future (Lockwood & Kunda, 1997). All these attributes need encouragement to help overcome a lack of confidence and sense of pessimism witnessed amongst females within a STEM context.

Previous research has indicated that the gender of a role model is also important (Bages et al. 2015; Darmody & Smyth, 2005; Dury et al., 2011). In the case of female aspirants, inspirational female role models and not male role models have proved successful (Rosenthal et al., 2013). Unfortunately, research data indicates that there have been, and still are a lack of suitable female role models (Dury et al. 2011; Fraser, 2014) and a shortage of women taking to public platforms to share their journeys (Wright, 2018). This is self-perpetuating and cyclical. If there are not many females studying STEM subjects in schools and taking up STEM careers then there will not be many who can become role models encouraging the next generation of young people to take up STEM careers and in turn become the next influential role models.

#### 4. CONCLUSION

'Conformity to social expectations, gender stereotypes, gender roles and a lack of role models continue to channel girls' career choices away from STEM fields' (Noonan & Laffarge, 2017).

The above quotation admirably sums up the conclusions to this paper concerning woman's under-representation in STEM, the part role models have played in the past and whether or not we still need them today. Having been in a privileged position, as a female teaching a STEM related subject for the past six decades, I hope that I have acted as a positive role model throughout that time. I have certainly tried to encourage all the females that I have come into contact with to have confidence in their ability to study and take up careers in various aspects of STEM. I have relished helping them to develop their capability and achieve success and above all to enjoy and become passionate about what they have learnt. STEM needs as many female advocates as possible if we are to overcome the problem of female under-representation. If we do not, there will continue to be serious consequences for STEM and it will remain an area of global concern. So, the answer is 'Yes' we still need relevant, genuine, confident and yet humble, successful, passionate, encouraging and generous role models today, and for the foreseeable future.

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# Changing Competencies, Changing Attitudes? How Teachers Become Technology Teachers

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There are not sufficiently many trained technology teachers in compulsory schools in Sweden. One way to meet the need is to train teachers that teach other subjects in technology. Professional development courses are offered within a national programme, called *Lärarlyftet* ('Boost for teachers'). The aim is to give the participants sufficient content knowledge and subject-specific pedagogical knowledge to enable them to teach technology according to the current syllabus. In this study, 14 lower secondary school teachers participating in a professional development course in technology in *Lärarlyftet* are followed. The course consists of three semesters of part time studies, corresponding to 30 weeks of full time studies (45 ECTS credits). The participants, with different disciplinary backgrounds want to broaden their competences in technology. The purpose of the study is to investigate how teachers' perception of the technology subject and their own knowledge of it. The study is longitudinal, with interviews at the onset of the course, in the middle, and near the end. During the course, the respondents experience increased self-confidence concerning teaching technology. They are also more competent in describing their own strengths and shortcomings. Their main worries at the end concern insufficient knowledge about planning and assessment, and also the lack of certain technical skills and shallow knowledge concerning engineering science-based content such as electronics and automatic control. They also express that their own view of the technology subject has been positively enhanced and that it has a legitimate place as an independent subject in the curriculum.

*Key Words: Technology teachers, Teacher training, Teacher competence, Professional development.*

## 1. INTRODUCTION

To work as a teacher in Sweden, both a degree from a teacher education programme and a teachers' certificate are needed. The certificate is issued by the National Agency for Education (Skolverket) and concerns one or more subjects for one or more age ranges. Certified teachers may teach other subjects than they are certified for, but grading must then be done by a certified colleague.

There is a shortage of certified technology teachers, and technology is often taught by teachers (mainly in science studies or sloyd) who lack a technology certificate. One way to remedy this is to offer professional development courses within the academic outreach program *Lärarlyftet* ('Boost for teachers') instigated by the Swedish government and led by the National Agency for Education. Through the courses offered within the project, teachers can complement their qualifications. Courses in different subjects are offered through universities around the country and should provide sufficient knowledge for a certification to teach the subject.

In this study, a group of teachers participating in a professional development course in technology is followed. The course takes place at a Swedish university and consists of three semesters of part-time studies, corresponding to 30 weeks of full time studies (45 ECTS credits). After finishing the course, the participants can apply for a teaching certificate in technology for lower secondary school (pupils aged 13–16).

All participants need to have a teaching degree before applying to the course. They must also be employed as teachers and teach technology without having adequate education in the field. Their school principals must also grant permission for participation as they work as teachers during the course. The students come from all parts of Sweden.

The course in question consists of seven modules chosen to be relevant to the Swedish curriculum. They include subject studies as well as educational studies:

- Introduction to technology in compulsory school (history of the subject, planning, assessment and the design process in education)
- Design and product development (subject studies)
- Industrial systems (subject studies and educational studies)
- History of technology (subject studies)
- Computers and programming (subject studies)
- Electrical engineering (subject studies)
- Models, simulations and experiments in technology education (mainly educational studies)

## 2. AIM AND RESEARCH QUESTIONS

The purpose of this study is to increase the knowledge about how teachers' understanding of, and attitudes toward, the technology subject in lower secondary school develops while learning about it through a professional development course.

The research question is:

- What development of teachers' perception of the technology subject is observed after a subject education course?

## 3. METHOD

In this longitudinal study, data was collected, over time of the course, in several different ways. An online survey was used to ask questions about content in the technology subject. The course evaluation, a survey intended for course development, was studied. Interviews were conducted. The interviews were done in two different ways: 1) an oral survey using the teachers' mobile phones, and 2) one-to-one interviews. The one-to-one interviews were conducted with volunteers and took place in connection with teaching activities at the university. They lasted between 45 and 60 minutes.

This paper will present and discuss the results from the one-to-one interviews with three teachers. They were interviewed at the onset of the course, in the middle and at the end. As there were no clearly discernible differences between the results from the beginning and the middle of the course, the middle interviews have been omitted (see the selected markings in table 1). The interviews were semi-structured (Kvale, 1997) and approximately followed a questionnaire with follow-up questions for clarification. All interviews were recorded and transcribed.

Table 1. Timeline for data collection

Time Frame	Start AS 15	During term AS 15	Start SS 16	During term SS 16	Start AS 16	During term AS 16	End AS16
	Short-answer interviews	Interviews	Short-answer interviews	Interviews	Short-answer interviews	Interviews	
	Survey						Course evaluation

(AS – autumn semester, SS – spring semester)

### 3.1. Respondents

Over the course period, 14 teachers participated in the course and participated in some interviews and/or surveys. They have different disciplinary backgrounds. A majority are science teachers, but they also teach mathematics, crafts or social sciences. Only a few teachers participated in all the data collection activities. This paper will discuss the statements made by three teachers. Two of them have some teaching experience in technology before the course, but the third did not.

### **3.2. Data analysis**

A modified version of the Pedagogical Content Knowledge (PCK) framework developed by Magnusson, Krajcik and Borko (1999) has been used as a lens in the analysis. The original model includes five categories and is intended for the study of science teaching. The modified model is adapted for technology education purposes (Fahrman et al., 2017). It consists of the following categories:

- a) Knowledge of the technology curriculum,
- b) Knowledge of students' understanding of technology,
- c) Knowledge of instructional strategies for teaching technology,
- d) Knowledge of assessment in technology, and
- e) Orientation towards technology teaching.

## **4. RESULTS**

The teachers have prior to the course, moderate to none knowledge of teaching the subject. They convey a view about technology teaching they met over time at their workplaces and describe a subject with strong focus on design – and – make traditions where building and constructing models often are mentioned.

The teachers' responses concerning their own knowledge about, and attitudes towards, teaching technology early in the course (during first semester) and near the end (during third semester) (see table 1) are classified using the PCK framework.

### **4.1. Orientation towards technology teaching**

#### *4.1.1. Early in the course*

Technology is described as a subject that is difficult to grasp, with a syllabus that is difficult to understand. The respondents, therefore, try to connect the technology content to their other subjects, and to teach about what they feel confident about, avoiding content that they do not master. Furthermore, they describe how they and their pupils find the subject to be fun and rewarding. The possibilities for interdisciplinary education are ample, as are activities related to everyday life. The technology subject is described as combining theoretical parts and hands-on activities. Particularly the design process ('the technical development process' in the syllabus' words) is regarded as important.

The respondents find that technology education at their schools often is neglected and that the subject does not have the same space or status as other subjects. However, they believe that this is changing and that schools are working to create better technology education.

#### *4.1.2. Late in the course*

The teachers describe an increased confidence concerning technology teaching. They claim that they have developed their content knowledge and learnt a lot about the teaching practice. They talk about teaching by problematizing the content, to discuss and actively investigate or construct. One of the teachers says that he does not think his way of teaching has changed, but his understanding of the subject certainly has. He says:

The reason of teaching is the same, to know the students' level and to have a stable and structured approach. To do lessons in a clear way with a structured learning, that is essential in all subjects. So I do not think there are that many differences actually in education. I believe it's more about my own understanding of the subject. It is probably more that which has changed, than the teaching itself.

Another teacher expresses how much more important technology education seems to him now and how important it is to distinguish it from other subjects; it is a subject with its own platform.

They do, however, also express that subject knowledge varies considerably across the vast range of themes. In some, such as technical systems, they consider themselves well-equipped for teaching. In others, such as electronics, they see themselves as inadequately prepared. They also have different views about the need for in-depth subject knowledge. One of them expresses that in-depth subject knowledge is important. Another says that information can always be looked up and that knowing how the subject is taught and planned is more

important for a teacher. The third points out the importance of a coherent teaching plan and teaching aids for all levels of the school system (cf. Nordlöf et al., 2017).

## **4.2. Knowledge of the technology curriculum**

### *4.2.1. Early in the course*

The respondents express an uncertainty about the subject's content. They find it difficult to grasp and want clarifications concerning the writings in the syllabus: What is the core of the subject? What does it include? How should the grading criteria be interpreted? They perceive the design process (in the Swedish syllabus referred to as 'the technological development process') as being an especially important part of the technology subject.

They describe how there are some themes listed in the curriculum that they feel insecure about, such as automatic control, pneumatics and technical systems. They also describe how other parts of the core content are closely related to subjects that they already teach, which makes it easier to understand and teach, examples include mechanical transmissions and components. One of the respondents teaches Swedish, and she found that she felt confident in teaching about words and concepts in technology. She says '... Learning is about language development, learning new concepts; one must be able to express what one knows in different ways.'

They also describe that the subject has many cross-disciplinary topics that can be taught thematically and that learning in technology involves obtaining a technological language.

### *4.2.2. Late in the course*

The teachers describe that they have developed a greater understanding of the nature of the technology subject and, thus, feel more confident to teach it. They emphasise that their understanding of large technological systems (socio-technical systems), as well as their ability to educate about them, has increased. Teaching about systems can help pupils develop several of the subject's special skills in relation to large sections of the core contents. Thereby, the system view can be used as a planning and teaching method; it is more than just a type of content. They still experience uncertainty concerning specific themes, such as electronics.

Even though they experience a developed understanding of the technology subject, they express an uncertainty in teaching specific topics. One teacher says '... I would love to have even more material that is directly useful, like lesson plans and so on.'

## **4.3 Knowledge of students' understanding of technology**

### *4.3.1. Early in the course*

The respondents describe a great variation in their pupils' understanding of technology. They often have a good grasp of engines, mopeds and the use of computers and mobile telephones but lack knowledge about, for example sustainable development and technology's impact on society.

### *4.3.2. Late in the course*

The respondents' stress that pupils will be more motivated if they experience technology teaching that is relevant, realistic and concern phenomena that are present in their pupils' everyday lives. They declare that knowledge about large structures, systems and principles are more important than details.

## **4.4 Knowledge of assessment in technology**

### *4.4.1. Early in the course*

Assessments and grading are among the respondents' greatest worries. As they are uncertain about the subject's nature, they are also uncertain about what to assess. Assessment of design and construction work is regarded as especially difficult, even more so if it is carried out in groups. One of the teachers describes that she experiences the grading process as extremely inequitable, as there are no national tests in technology and how difficult it is to get high grades depends on your teacher.



#### *4.4.2. Late in the course*

At the end of the course, the teachers still express concerns with the practice and knowledge of assessment in the technology subject. They request more suggestions, guidelines, examples and exercises. It is especially difficult within subject areas they feel insecure about. One teacher means that it is important to raise questions like ‘What are the differences between developed reasoning and well-developed reasoning [expressions used in the syllabus] in technology?’ and ask how this can be understood.

### **4.5 Knowledge of instructional strategies for teaching technology**

#### *4.5.1. Early in the course*

The instructional strategies that the respondents describe are those that are commonly used at their respective workplaces. They describe teaching as based on design and construction: on solving technical problems. But they find it difficult to grasp parts of the subject content, and therefore, how to teach it. Planning lessons is difficult when you do not fully understand what the examples in the syllabus mean. The respondents address the importance of understanding the whole width of the technology subject: the impact of technology on society and individuals, the democratic aspects of technology, sustainable development and gender aspects related to technology. They express a need for ‘best practice’ examples of teaching, as well as subject knowledge. One teacher says that she feels insecure in her role as a technology teacher even though she has several years of teaching experience in other subjects; she finds the hands-on practical work to be difficult. She says:

The non-practical parts I can handle, I can learn through reading, I can convey knowledge and I can get the kids to work ... As an experienced teacher I know a lot about methodology and didactics, so what I have trouble with and what I want to learn is more practical handling.

Another teacher expresses that parts of his knowledge about science teaching are also useful when teaching technology, but that he needs to develop his skills concerning designing and making. One respondent argues that teachers who are insecure about teaching certain content matter, like automatic control, probably do not focus on working with that content.

#### *4.5.2. Late in the course*

The teachers feel much more confident about teaching the subject, having developed more subject knowledge. They describe how their teaching is more focussed. Before the course, their lessons did not always have a clear purpose, which was especially apparent when their pupils were involved in constructing and making. One of them says:

Not as much “doing” anymore. I would say that it has become much more theoretical in comparison to what it was before. Like with solid mechanics theory for example. We no longer construct bridges without talking about pressure, elasticity and tensile strength.

One of the respondents finds it challenging to use parts of the course’s contents, as it is too advanced for school purposes and has to be transformed to fit 13 - year - old students.

One of the teachers describes that the subject requires good planning and suitable teaching materials. He further states that the best technology lessons last for 1.5 hours and consist of a lecture section followed by hands-on work. The respondents also claim that working in large projects is more prominent in technology than in most other subjects.

Teaching technology need not be different from other subjects. One respondent states that the main problems and opportunities are the same: one needs to know the pupils’ level and have a structured approach with common features. The importance of using content that is closely related to the pupils’ everyday life is also stressed. If they play Pokémon Go, use that to teach about GPS and computers.

## 5. DISCUSSION

The research question concerns what development of teachers' perception of the technology subject can be observed after partaking in a professional development course. Reports and previous research studies emphasises the importance of knowledgeable teachers for pupils' learning (Association of Swedish Engineering Industries, [ASEI], 2005; Bjurulf, 2008; Hartell et al., 2014; Mattson, 2002; Skolinspektionen, 2014).

The informants have partaken in a three semester course and are all trained and experienced teachers. They have, however, little or no experience in teaching technology. They describe what they know and what they don't know and, thereby, how they understand the nature of the technology subject. Through the study we conclude that the participating teachers' views of the subject have been positively enhanced; they express that the subject has its legitimate place in school as an independent subject. The teachers' emphasis increased self-confidence in teaching technology after taking the course.

At the same time, they have also become more aware of their shortcomings (concerning content knowledge as well as teaching strategies). They express uncertainty about planning and how to implement teaching regarding certain content. We can note that there is still uncertainty associated with the design-and-make process, especially pupils actual making. The teachers describe their uncertainty about this at the beginning of the education. Later, they express developed subject content knowledge. However, for some topics, we cannot link this to their being more secure in dealing with the teaching practice. The course provides room for discussions and planning, but not all of them have had the opportunity to practice in the classroom.

Furthermore, the teachers still feel that they lack necessary content knowledge in some areas, especially within those closely related to engineering sciences, such as automatic control and electronics. Potential problems related to how to teach and assess creativity and technical skills such as solving ill-defined problems, are not discussed, even though those aspects are mentioned in the syllabus (Skolverket, 2016) and is in the international technology education literature often put forward as important characteristics of the subject (e.g. Kimbell & Stables, 2007; de Vries, 2005). Overall, the respondents had little to say about their Knowledge of students understanding of technology (cf. Norström, 2014).

The respondents describe how their subject knowledge and knowledge about the curriculum has increased. They also say that they have developed a greater focus on what content to teach and how it can be conveyed in the classroom. These improvements belong to the category Knowledge of Curriculum; they concern a type of knowledge that can easily be represented in books or described during lectures. However, even though the respondents have a greater knowledge of technology they still express uncertainty in connection to assessment. Whether this is a specific concern in the assessment of the subject of technology, or if their concerns are of a more general nature is unknown. Expressions open to interpretations, like 'differences between developed reasoning and well-developed reasoning', can be found also in other subjects' syllabi and are often regarded as vague.

The respondents perceive technology as a more important subject after taking part in the course and the nature of technology teaching has become clearer. This development is part of their Orientation towards technology teaching.

The vague syllabus gives many possibilities for interpretation, which provides opportunities for the experienced teacher but may lead to feelings of insecurity and confusion for the beginner. This could be problematic and reinforce the view of the subject as unclear and seldom taught according to the syllabus (Skolinspektionen, 2014). Skills and knowledge about actual teaching, planning and assessment are difficult to teach, as they are difficult to describe in writing and tend to develop through practice. This is most likely an important reason for why the participants do not feel that their Knowledge of Assessment and Knowledge of Instructional Strategies have developed to an adequate level during the course. The respondents' statements highlight the importance of an education for prospective technology teachers that provide both good subject knowledge and a familiarity with teaching the subject.

## 6. CONCLUDING REMARK

This study uses data from just one professional development course for teachers. To what extent the results are specific to that course cannot be determined through the available data.

Through active participation in the course, the teachers have developed their perceived PCK within some of the categories. This study shows that their knowledge development is positive and that the students generally are satisfied in participating in the course. However, we can conclude that the course is not enough to become a full-fledged technology teacher; the authors believe that more familiarity with actual teaching is necessary.

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# A Global Analysis of how High School Technology Activities are Preparing Students for the 21st Century

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As the complexity of the global economy increases into the 21st century, so too do the needs of industry and education. Are technology education program curriculum and activities successfully addressing those needs in secondary high schools, so students might achieve the necessary 21st century skills? Are those needs consistent among the industrialized nations of the world? Are those institutions addressing such needs in similar fashion, that is, by using similar lessons and laboratory activities? Using content analysis, the researchers sought answers to the aforementioned questions for New Zealand, England, Sweden, and the United States. Content analysis enabled the researchers to make inferences regarding similarities and differences in what those countries identify as the most important 21st century skills for all high school students in each respective country. In addition, content analysis permitted the researchers to validate those inferences while drawing conclusions about the social impact of such curriculum and activities within each respective country. Although the researchers found no significant statistical differences in the skills the countries emphasized or addressed in their respective lessons, analyses did reveal that secondary education classes appear to be preparing graduates with 21st century skills, as are needed in global economic development.

*Key Words: 21st Century, Technology, Skillsets, Evaluation, Outcome.*

## 1. INTRODUCTION

As the economies around the globe continue to recover and expand from the Great Recession of 2007-09, labor's share of national income continues to decline in the larger economies (Karabarbounis & Neiman, 2017). Not surprisingly, every sector of the economy has witnessed extraordinary advances in information technology and telecommunications. With high-speed internet, the barriers for information exchange have eroded, leading to increased research and development, yielding new scientific and technological breakthroughs. Advances in science and technology lead to economic growth, leading to the expansion of economic activity, translating into job creation, product growth, and increased sales and national income. "As new technology is developed, corresponding changes must be made in retraining the current workforce as well as in educating the future workforce. Education and training must be dynamic and adjust and adapt to changes in technology" (Bevins, 2012, p. 10). The importance of technological literacy and technology education must move to the forefront. However, those who believe strongly in a liberal arts education often do not agree, unable to see how that liberal arts and technology education go hand-in-hand, creating a more productive, better equipped, educated citizenry. The magnitude of economic success in countries will depend upon how well students transition from the classroom to the labor force. The rate of which depends upon how well educational institutions prepare students with the 21st century skills the economy and society demand.

In reviewing technology education curriculum for the high school levels in the selected countries of England, Sweden, New Zealand, and the United States, movement to better equip students in those skills appears to be in a similar direction. Greater focus is being placed on the transformation of the student. That is, how can the curriculum increase student's competitiveness both now and in the future for a global economy? Not only have

these countries improved their curriculum with new standards, they have also connected their curriculum to other STEM and liberal arts subjects. Students are developing better decision-making and communication skills through the use of real-world applications. They identify existing problems in society, collaborate and develop possible solutions, and compare the costs and benefits of implementing each solution.

## 2. RESEARCH QUESTIONS

The intent of this study was to determine if differences exist in what countries identify as important 21<sup>st</sup> century skills for high school students. To analyze this problem using Metiri (2003) skillsets for 21<sup>st</sup> century learning, the following research hypotheses were tested.

$H_0^1$ : There are no significant differences in how the four selected countries address *digital-age literacy* in their respective technology education lessons, that is, in the skills addressed from the *digital-age literacy* skillset.

$H_0^2$ : There are no significant differences in how the four selected countries address *inventive thinking* in their respective technology education lessons, that is, in the skills addressed from the *inventive thinking* skillset.

$H_0^3$ : There are no significant differences in how the four selected countries address *effective communication* in their respective technology education lessons, that is, in the skills addressed from the *effective communication* skillset.

$H_0^4$ : There are no significant differences in how the four selected countries address *high productivity* in their respective technology education lessons, that is, in the skills addressed from the *high productivity* skillset.

$H_0^5$ : Secondary technology education classes are not preparing graduates with 21<sup>st</sup> century skills, as needed for global economic development.

## 3. LITERATURE REVIEW

The students in today's secondary educational settings are inundated with technology in all facets of their lives. Yet much of the school curriculum still does not cover the essential 21st century skills these learners need for future educational and economic success. The Metiri Group (2003), a policy analysis think tank, analyzed seventeen studies including National Educational Technology Standards (NETS) for Students (2000), Standards for Technological Literacy: Content for the Study of Technology (2000), 21st Century Literacy in a Convergent Media World (2002), and Digital Transformation: A Framework for ICT Literacy (2002). Based on analyses of these sources, the group posits a recommendation for what 21st century skills students need to possess for success in the digital age. "The sheer magnitude of human knowledge, world globalization, and the accelerating rate of change due to technology necessitate a shift in our children's education – from plateaus of knowing to continuous cycles of learning (Metiri, 2003, p. 5). The Metiri Group categorized learning into four distinct areas with a strong underpinning of academic achievement to attain 21st century learning outcomes. These areas are digital-age literacy, inventive thinking, effective communication, and high productivity with subcategories in each area to further delineate particular literacies needed for success in the ever-evolving technology-rich world in which they will live and work. Figure 1 lists these skills and their subsets.

In addition to the Metiri Group, the National Association of Colleges and Employers (NACE), has worked to alleviate the skills gap between employers and college graduates since 1956. In 2016, employers identified the skills shown below, ranking them according to importance. These skills were very much aligned with those of the Metiri Group. The educational community continues to think these outcomes are important (Mizar, 2018; Osborne, 2018; Ross, 2018), as evidenced by being the theme of the 2016 PATT Conference. At issue is to whom belongs the responsibility for educating and/or training students in these skills. Such skills are not necessarily acquired in specific courses. Instead, they must become part of a curriculum and thus, acquired through lab and other hands-on classroom activities in a host of courses.

- Ability to verbally communicate with persons inside and outside the organization
- Ability to work in a team structure
- Ability to make decisions and solve problems
- Ability to obtain and process information
- Ability to analyze quantitative data
- Technical knowledge related to the job
- Proficiency with computer software programs
- Ability to create and/or edit written reports
- Ability to sell or influence others (NACE, 2016, Figure 1)



Figure 1. Metiri Group Skills for the 21st Century.

The four countries, England, New Zealand, Sweden, and the United States, were chosen for this study, because of the desire by researchers to extend the investigations completed by Ritz and Bevins (2016). The earlier study recommended that “the technology education community should revisit its goals for learners and possibly re-design some of its goals. Changes might be made to better prepare students for the 21st century through the study of technology education” (Ritz and Bevins, 2016, p. 9). With that in mind, the focus of this study shifted to the technology education classroom. Are lesson plans addressing the 21st century needs of industry by incorporating activities that promote the development of 21st century skills for student and economic development?

### 3.1. England

England’s Department for Education reformed the standards for design and technology curriculum in 2015, with implementation beginning in 2017. There was support for increased use of STEM concepts along with concern for lack of specialism in the certificate (Department for Education, 2015a). The curriculum for design and technology utilized specific aims with a focus on the iterative design process of exploring, creating, and evaluating. A strong tie-in with knowledge from other disciplines – mathematics, science, art and design, computer, and the humanities is expected. Crosswalks with science and mathematics are included to ensure students demonstrate competency through hands-on or applied experiences. England’s curriculum design centers on 21st century skills in their objectives specifically, “decision making skills,” “ambitious and open to explore and take design risks,” and “communicate their design ideas and decisions... for different audiences” (Department for Education, 2015b, p. 4). The Department for Education lists the following aims and

objectives for design and technology GCSE (General Certificate of Secondary Education) in design and technology (Department for Education, 2015b).

- demonstrate their understanding that all design and technological activity takes place within contexts that influence the outcomes of design practice
- develop realistic design proposals as a result of the exploration of design opportunities and users' needs, wants and values
- use imagination, experimentation and combine ideas when designing
- develop the skills to critique and refine their own ideas whilst designing and making
- communicate their design ideas and decisions using different media and techniques, as appropriate for different audiences at key points in their designing
- develop decision making skills, including the planning and organization of time and resources when managing their own project work
- develop a broad knowledge of materials, components and technologies and practical skills to develop high quality, imaginative and functional prototypes
- be ambitious and open to explore and take design risks in order to stretch the development of design proposals, avoiding clichéd or stereotypical responses
- consider the costs, commercial viability and marketing of products
- demonstrate safe working practices in design and technology
- use key design and technology terminology including those related to: designing, innovation and communication; materials and technologies; making, manufacture and production; critiquing, values and ethics (Department for Education, 2015b, p. 4)

### **3.2. New Zealand**

The New Zealand Tertiary Education strategy for 2014-2019 focuses on strengthening industry training and strengthening support for science and engineering provisions. It understands the need to focus on equipping their citizenry with skills and qualifications needed to compete in the labor market and support an innovative and successful New Zealand. The New Zealand Ministry of education research states that learning must be personalized and education systems must transition from the industrial concept to a scenario where the learner is the focus of the curriculum not the curriculum content (New Zealand Government, 2014a). The learning must be a collaborative community with learners and teachers working to solve complex problems. The learning must be culturally and linguistically diverse to ensure competence in a global society as well as having a future focus to keep learners involved in lifelong learning (Bolstad, et al., 2012, p. 5). The New Zealand Curriculum identifies five key competencies that correspond with 21st century skills:

- Thinking
- Relating to others
- Using language, symbols, and texts
- Managing self
- Participating and contributing (New Zealand Government, 2014b, para. 4).

These competencies promote the need for learners to demonstrate “capabilities they possess as well as those they need to develop to live and learn today and in the future” (New Zealand Government, 2014b, para. 3).

### **3.3. Sweden**

Schooling is mandatory for all children in Sweden between the ages of seven and sixteen. The subjects studied during these nine years are described in the national curriculum and are mandatory. Each subject is described by an introductory text explaining its purpose, a set of skills that pupils are to develop through training in the subject in question, and a list of core content (Fahrman, Gumaelius, & Norstrom, 2015). Under the curriculum for compulsory education, schools are responsible for ensuring that every student attending compulsory school is able to use modern technology as a tool in searching for knowledge, communication, creativity and learning (Sweden.se, 2018).

Technology was introduced as a mandatory subject for all pupils in the 1980 curriculum. At that time technology was closely linked to the science subjects (biology, physics, and chemistry). In the curriculum, it was not clearly defined in what ways technology differed from the established science subjects, and in many schools it was lost among them. Many pupils were not even aware of having studied technology. When the

national curriculum was revised in 1994, technology became a subject separate from science, with a more explicit interdisciplinary nature (Fahrman, Gumaelius, & Norstrom, 2015).

In the curriculum of 2011, the characteristics of the technology subject became clearer, as evidenced through the work of the Swedish National Agency for Education (Skolverket).

Teaching in technology should aim at helping the pupils to develop their technical expertise and technical awareness so that they can orient themselves and act in a technologically intensive world. The abilities pupils are expected to develop are: identify and analyse technological solutions based on their appropriateness and function, identify problems and needs that can be solved by means of technology, and work out proposals for solutions, use the concepts and expressions of technology, assess the consequences of different technological choices for the individual, society, and the environment, analyse the driving forces of technological development and how technology has changed over time (Skolverket, 2011, p. 254).

The first decade of the new millennium witnessed, greater emphasis on the use of digital tools, both in and outside the classroom. In addition to its impact on instruction, digital technologies changed how students obtained, processed/analysed, and communicated information to others (Alexandersson & Limberg (2009). The Swedish government saw digital literacy as a means to achieve “positive social development.” As a result, “five goals were set: digital skills, digital security, digital innovation, digital leadership and digital infrastructure” (Swedish Ministry of Enterprise and Innovation, 2017).

### **3.4. United States**

“With its entire history as a ‘learn through doing’ curriculum, technology education has always been laboratory based” (Ernst & Haynie, 2010, p. 70). “Doing activities provide people with feelings such as gratification, a sense of accomplishment, and a measure of what one knows and is able to do. Most importantly, doing is a major process for learning and gaining knowledge” (Moye, Dugger, & Starkweather, 2018, p. 4). While “doing” has positive results in learning, the preparation of those activities and the completion of those activities in the classroom requires a great amount of time and resources. Were this not the case, 94% or 5,572 out of 5,898 elementary and secondary STEM teachers would have done more classroom activities (Moye, Dugger, & Starkweather, 2018).

“In the U.S., education is primarily the responsibility of the states or local government. The U.S. Department of Education has limited power and responsibility concerning education at the state or local level” (Dugger, 2016, Slide 12). Organizations, such as the International Technology and Engineering Educators Association (ITEEA), the International Society for Technology in Education (ISTE), and the National Assessment Educational Progress (NAEP) provide technology standards, lesson plans, and other information that may be used as guides by school administrators and teachers as well as politicians. Interestingly, technology has brought down the walls separating economies throughout the world as well as those separating the disciplines within academic buildings and across campuses. To prepare students for the workforce and/or higher education, the education process must be integrative. Disciplines can no longer be taught mutually exclusively or independently of one another. Students must be able to think critically; problem solve; and communicate the thought process, findings, solutions, and costs and benefits of the solutions to others. In order to “grade” this process, NAEP developed an assessment instrument for grades 4, 8, and 12. The first assessment was administered to eighth grade students in 2014. The assessment focused on three areas: technology and society, design and systems, and information and communication technology.

In line with the hands-on emphasis, the National Governors Association (NGA) is currently focused on “work-based” learning. Governors across the U.S. understand they are responsible for economic development within their respective states and therefore, realize growth in the economy will require building bridges between education and business. Building and strengthening relationships between the two creates a win-win situation for both involved, as shown in Table 1 (Hauge, K., 2018, p. 4).



Table 1. Benefits of Work-based Learning.

Participant Benefits	Business Benefits
<ul style="list-style-type: none"> <li>• Apply content learned in the classroom;</li> <li>• Explore career options and make informed decisions about education and work;</li> <li>• Build soft skills</li> <li>• Gain work experience that can launch a career; and</li> <li>• Interact with and learn from adult mentors.</li> </ul>	<ul style="list-style-type: none"> <li>• Nurture student interest in careers in their industry</li> <li>• Build partnerships with schools;</li> <li>• Increase employee retention and productivity</li> <li>• Audition potential job applicants; and</li> <li>• Develop a highly skilled workforce.</li> </ul>

From Hauge, K. (2018). States Continue Advancing Strategies to Scale Work-based Learning. Retrieved from [https://www.nga.org/files/live/sites/NGA/files/pdf/2018/EO/Products/0118\\_States%20Continue%20Advancing%20Strategies%20to%20Scale%20Work-Based%20Learning.pdf](https://www.nga.org/files/live/sites/NGA/files/pdf/2018/EO/Products/0118_States%20Continue%20Advancing%20Strategies%20to%20Scale%20Work-Based%20Learning.pdf)

Most recently, employers have gone beyond their search for individuals “who possess attributes like problem-solving, teamwork, communication, and leadership skills” (Gray & Koncz, 2018, para. 2). They now want individuals who have work experience through internships, co-ops, or previous employment (Gray & Koncz, 2018). This desire by employers demonstrates how important it is to include technology education in a liberal arts curriculum.

#### 4. METHODOLOGY

To determine if differences exist in what the four countries identify as the most important 21st century skills for high school students, a content analysis was used to analyse two technology education lesson plans from each of the four countries, England, New Zealand, Sweden, and the United States. As a follow-up to a study conducted by Ritz and Bevins (2016), convenience or non-probability sampling was used in obtaining the lessons. Email requests for the lessons were sent to leading educators in the four countries. After obtaining the lessons, each author of this study reviewed each lesson independently, identifying which Metiri skills were the focus of each lesson. Once all reviews had been completed, content analysis was conducted on the identified skills, investigating whether differences in the skills and thus, skillsets emphasized existed among the four countries. The four countries were chosen for this study, because they were the focus of Ritz and Bevins (2016). In addition, the researchers were more familiar with the current technology education research conducted within these countries.

To analyse content or text quantitatively, a finite set of steps or procedures was used to compare important words the researchers selected for entering into KH Coder, a free software program chosen by the researchers. The software used computational linguistics to analyse and synthesize skills identified by the researchers. In this study, content analysis examined “word” or “skill” similarities in the technology education lessons from England, New Zealand, Sweden, and the United States. Chi-square analyses were used in comparing each country’s lessons to the Metiri skillsets for the 21st century.

#### 5. RESULTS

The eight technology lessons, two from each of the four countries, England, New Zealand, Sweden, and the United States, were associated with 57 of the 68 skills from the four 21<sup>st</sup> century Metiri skillsets, *digital-age literacy*, *inventive thinking*, *effective communication*, and *high productivity*. Fifty-seven individual skills were identified by the researchers as being emphasized by one or more of the technology education lessons. Each skill appeared on average 4.25 times, with approximately 14% or 8 of the skills appearing only once, 23% or 13 appearing twice, and 19% or 11 appearing three times. The 57 unique skills were used a total of 242 times in describing the 21<sup>st</sup> century skills emphasized in the lessons. Of the 242 times, approximately 33% of the skills were associated with the high-productivity skillset; 28%, the inventive thinking skillset; 21%, digital-age literacy; and 19%, effective communication.

When the skills and country associations were analysed using “random walks,” as shown in Figure 2, Sweden had the largest number of edges, that is, unique skills associated with its technology education lessons. Eighteen of the Metiri skills were represented in Sweden’s lessons, 16 in the U.S. and England, and 13 in New

Zealand’s lessons. The darker the edge, the stronger the association between the country and the skill, such as is the case with Sweden and the following skills from its lessons: technical, environment, engineering, and maintenance. England and Sweden had the largest number of skill associations, nine: engineering, team, write, design, model, materials, technology, materials, and products. New Zealand and England had the fewest, five: technology, materials, model, design, and problem. The size of the bubble or circles indicated the extent to which the skill was identified by the reviewers as being an emphasis in the technology education lessons. Not surprising, technology and materials were identified most in the lessons.

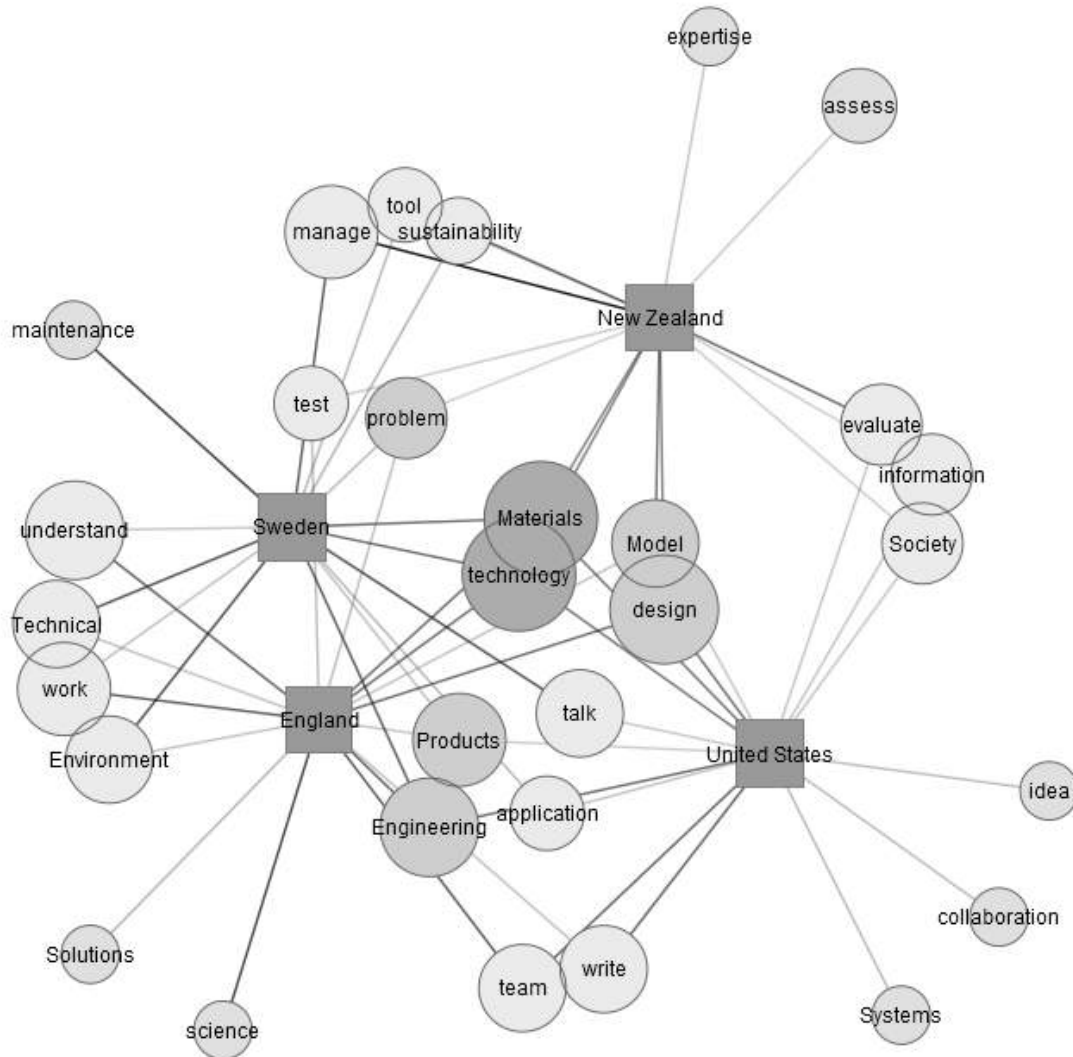


Figure 2. Skills and Country Associations Determined by Random Walks.

The frequencies of skills identified in the lessons from each country are shown in Figure 3 and Table 2. The frequency of skills identified in each country’s technology education lessons is denoted by the color in the heat map in Figure 3 and the numerical counts and percentages in Table 2. The darker the color in the heat map, the greater the frequency of skills. For example, the more frequent Metiri skills identified in the lessons from England, New Zealand, and the United States were from the inventive thinking skillset. England’s two lessons included 28.8% of the skills categorized under that skillset, with New Zealand’s lessons including 34.4% and the U.S., 29.5%. The more frequent Metiri skills identified in Sweden’s lessons were from the high productivity skillset, accounting for 29.3% of the skills in that skillset. The lower frequencies of the Metiri skills for all of the countries were from the effective communication skillset: England – 13.6%, New Zealand – 15.6%, Sweden, 17.2%, and the U.S. – 18.0%. Overall, England’s two lessons included 89.83% of the Metiri skills; New Zealand, 93.76%; Sweden, 91.38%; and the U.S., 88.52%. While the range of the frequencies across skillsets appeared to be quite large, 13.6 to 34.4, the range across countries for each skillset was not, as proven statistically in Table 2.

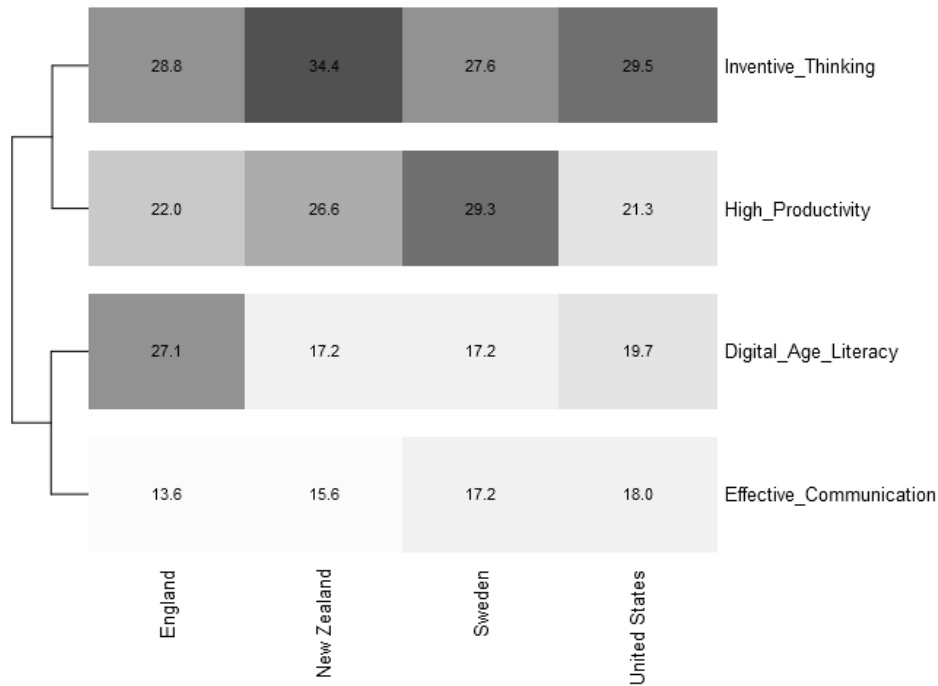


Figure 3. Technology Education Lessons Categorized According to 21<sup>st</sup> Century Skills and Country.

Chi-square tests were performed to determine whether significant differences existed across technology education lessons in regards to their alignment with the Metiri skillsets. As shown in Table 2, there was no significant difference in how the four countries address the Metiri skillsets. That is, there is no significant difference in the skills addressed from each skillset in each country's technology education lesson. The null hypotheses were not rejected for alpha levels of 0.05. With respect to each Metiri skillset, chi-square results, revealing no significant differences across lessons, were as follows:  $X^2(3, N = 49) = 2.43, p = 0.49$  for digital-age literacy;  $X^2(3, N = 73) = 0.79, p = 0.85$  for inventive thinking;  $X^2(3, N = 39) = 0.52, p = 0.91$  for effective communication; and  $X^2(3, N = 60) = 1.38, p = 0.71$  for high productivity. While the chi-square tests revealed no statistical differences in how the countries addressed each Metiri skillset in their respective lessons ( $H_0^1 - H_0^4$ ), the large percentages of Metiri skills identified in the lessons for each country suggest that secondary education classes are preparing graduates with 21<sup>st</sup> century skills, as needed for global economic development, rejecting the null hypothesis,  $H_0^5$ , that classes are not preparing those graduates.

	Digital-Age Literacy	Inventive Thinking	Effective Communication	High Productivity	N
England	16 (27.12%)	17 (28.81%)	8 (13.56%)	13 (22.03%)	59
New Zealand	11 (17.19%)	22 (34.38%)	10 (15.63%)	17 (26.56%)	64
Sweden	10 (17.24%)	16 (27.59%)	10 (17.24%)	17 (29.31%)	58
United States	12 (19.67%)	18 (29.51%)	11 (18.03%)	13 (21.31%)	61
Total	49 (20.25%)	73 (30.17%)	39 (16.12%)	60 (24.79%)	242
Chi-Square	2.43	0.79	0.52	1.38	
p-value	0.49	0.85	0.91	0.71	

Table 2. Technology Education Outcomes by Skillset Alignment with Metiri.

\*Significant for  $\alpha = 0.05$

## 6. CONCLUSIONS

The results of the study revealed that the four countries, England, New Zealand, Sweden, and the United States are very much aligned in their focus on the skills emphasized in their technology education lessons. When the null hypotheses were statistically analyzed using chi-squares, the researchers found no significant differences in how the four countries addressed each Metiri skillset in their respective lessons, that is, the skills addressed or emphasized in those lessons. The skills and frequency of skills within each skillset were quite similar in the lesson plans across countries, with the reviewers identifying more from the inventive thinking and high productivity skillsets and fewer from the digital-age literacy and effective communication skillsets. This is no surprise because we know with the advent of digital media, communication skills have decreased. Digital technology has moved the youth from being consumers of content to being producers of content. With Snapchat, Instagram, YouTube, and other animated/visualization software, the youth are leaving their digital footprints. While the researchers found no significant statistical differences in the skills the countries emphasized or addressed in their respective lessons, analyses did reveal that secondary education classes appear to be preparing graduates with 21st century skills, as needed in global economic development.

## 7. RECOMMENDATIONS

Given the small number of lessons analyzed in this study, the researchers recommend that additional time and resources be allocated to increase the number of lessons analyzed from each country. The researchers purpose further investigation to determine if the four countries in this study have expanded their approach to technology education into the elementary and middle levels of education, as research has shown early connections with technology education is critical for future student success. In addition, considerations for future study should include exploring how critical thinking, collaboration, and other 21st century skills are not only embedded in technology education courses, but are also cross-curricular, as studies have shown this approach to be most beneficial to students. Note: the sources for the eight lessons are shown below.

- England: The Institution of Engineering and Technology, <https://www.tes.com/>
- New Zealand: Technology Online, <http://technology.tki.org.nz/>
- Sweden: Curricula, Subject Plans, and Syllabi, <https://www.skolverket.se/laroplaner-amnen-och-kurser>
- United States: Grubbs, M., Cooperative Transport by Ants and Robots, [mdoddo@bcps.org](mailto:mdoddo@bcps.org) /
- Ritz, J., Technology & Assignment, [jritz@odu.edu](mailto:jritz@odu.edu)

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# Technology Teachers' Different ways of Thinking about Sustainable Development in Technology Education

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In this study, we investigate technology teachers' perceptions of sustainable development as part of technology education. Today's society requires education that evolves knowledge about technology beyond single innovations or artefacts towards technological systems that embraces social, environmental and sustainable issues. Education for sustainable development is one of the international educational goals and are included in the Swedish National curriculum (Skolverket, 2011). In all subjects in the Swedish curriculum, it is important to create learning conditions for sustainable development based on democratic grounds. Thus, research is needed to develop understanding of how to prepare young citizens for integration technology with sustainability. What pedagogical content knowledge is needed for teachers to teach technology and sustainable development? This study builds on previous research showing that teachers connect technology and sustainability to products and life-cycle analysis, from raw material to a product, which could be understood as a systemic approach. A systemic approach means to see parts and at the same time relate those parts to something whole. To better understand the systemic approach in relation to teaching technology and sustainable development, we interviewed technology teachers. We used content analysis of the transcribed interviews to code and identify themes and patterns. Our analysis revealed that recycling thinking, consequence thinking and system thinking describes teachers' perceptions and their teaching about technology and sustainability. We discuss this in relation to teachers' development of pedagogical content knowledge as well as their understanding of teaching technology and sustainable development.

*Key Words: Technology education, Sustainable development, Recycling thinking, Consequence thinking, System thinking.*

## 1. INTRODUCTION

There is limited research into technology teachers' pedagogical content knowledge, PCK (Williams, 2016). The notion of PCK was first introduced to the field of education by Lee Shulman (Shulman, 1987) and was described as the intersection of three knowledge bases coming together to inform teacher practice: subject matter knowledge, pedagogical knowledge, and knowledge of context. Subject matter content knowledge is described as knowledge that is unique to teachers and involves the teacher knowing how to fluidly take advantage of different teaching approaches that make a learning experience most suitable for the learners. In relation to our interests in teachers integration of sustainable development when teaching technology an important aspect of PCK is teachers own interpretations, capabilities and beliefs about sustainable development and the way it could be addressed through technology education (Pavlova, 2018). Earlier studies (see e.g. Elshof, 2005; Pitt and Lubben, 2009; Pavlova 2006) of teachers' perceptions of sustainable development in technology education shows that, what teachers consider important to teach, is to a high degree reflected in their classrooms. The readiness among technology teachers to teach sustainable development in technology classrooms also depend on and reflect the specific contexts that occur in each country (see studies about Canada, UK and Russian in Elshof, 2005; Pitt and Lubben, 2009; Pavlova 2006). Therefore, the Swedish context where this study is conducted might contribute with new research insights about teachers' teaching of sustainable development in technology.

Another important aspect to take into consideration is that there seem to be a technology-optimism among technology teachers concerning sustainability issues in relation to technology (Elshof, 2009, Knutsson, 2018). Sustainable issues" ...are typically reduced to technical matters of eco-innovation: superficial 'tinkering practices' and tacit hopes that environmental problems can somehow be subject to 'techno-fix'" (Elshof, 2009, p. 135). Knutsson (2018) and Pavlova, (2018) emphasize the need to include a more critical approach toward

technology and sustainable development in technology education. Therefore, it is of interest to find out more about Swedish technology teachers perception and their amount of critical approach towards sustainable development and technology.

### ***1.1. Aim***

The aim with this study is to investigate technology teacher's perceptions of sustainable development as part of technology education

Research questions:

- How does technology teachers' describe their teaching about sustainable development in technology education?
- What are teachers' main reasons for integrating sustainable development in technology education?

## **2. BACKGROUND**

### ***2.1 Technology education and education of sustainable development***

There is link between technology and sustainable development in policy documents in Sweden as well as in research and international reports (see e.g. Skolverket 2011; UNESCO, 2009) One reason for combining technology education and education for sustainable development (ESD), are the impact that all technology has on society, nature and sustainability as a tool for building capacity for living and learning. Technology is interwoven in our lives. Kamp (2006) emphasize that it is important to understand technology and sustainable development from a global perspective, to have an overall picture. In this way, students can become aware of the possibilities and consequences of technology in an international context. Technology developed and used in their own country affect people, communities and environments in many places on earth. Such awareness can help students to think about what we can expect from the future. In connection to the long-term goals in the Swedish curriculum the descriptions of the content Technology, it is noticeable that technology and sustainable development are linked. An example from the content description: "Effects of technology choices based on ecological, economic, ethical and social aspects, for example, in the development and use of biofuels and military equipment" (a content marked under the heading Technology, man, society, environment, for grades 7-9, Skolverket, 2011).

Research concerning technology education and ESD exists, but is not among the mainstream topics of research agendas (Pavlova, 2013). Studies of technology education and ESD are mainly discussed and focused on ecological design of products and the environmental impact or sustainability of products (Elshof, 2003; Stables 2009). The social and cultural aspect of ESD is insufficient in technology education research. If economic aspects of ESD occur in relation to technology education, it is described mainly as something negative and in relation to developed countries (Elshof, 2003). Filho, Manolas and Pace (2009) investigated initiatives in schools and universities that exemplified existing practices where technology education and ESD have been integrated. They emphasize two inter-related characteristics of the subject technology, "(a) that it is not just a know-how subject, but a know-why subject [...] and (b) that it provides students with the opportunity to resolve problems and hence extend human capabilities." (p. 161). This implies that technology education must become more student-centered and include a more interdisciplinary approach to integrate various issues, including sustainability. However, there is a lack of research on teaching and learning in and about technology connected to sustainable development, in particular regards the social, cultural and economic nature of sustainability. In order to provide additional insights in this direction; we want to investigate technology teacher's perceptions of sustainable development as part of technology education.

### ***2.2 A systemic approach in technology and sustainable development education***

System theory could be used as a framework for understanding the natural and constructed world by seeing it as a whole with the parts and relationships to the environment (von Bertalanffy 1968; Öqvist 2008). There are several system approaches that can be used to understand problems in the world; looking for the trouble spot in the system, making models of the system, identify human values in the system or to live in and experience the system (Churchman, 1967). Using a systemic approach to understand technology or sustainable development

implies a focus on the processes used to determine the outcomes of content or a procedure based on the experiences of well-defined and repeatable steps and an evaluation of the results. In education, a systemic approach is of particular value in the problem-solving situations where it is important to have a capability to enlarge the systems' borders and expose hidden dimensions of the system (Ben-zvi-Assarf and Orion, 2005). One important issue is that many problems in today's society are poorly structured such as environmental problems and poverty. To understand those problems, a systemic approach, with openness to different ways of thinking, is of particular importance and could be an inherent part of technology education. Therefore, it is of crucial interest to investigate if technology teachers use a systemic approach when teaching sustainable development and technology.

### 3. METHODOLOGICAL FRAMEWORK

Data in this study is based on semi-structured interviews with eight Swedish technology teachers' in compulsory school, grade 7-9. The eight teachers have participated in a pilot questionnaire survey that has been conducted earlier and volunteered to participate in a follow up in-depth interview. The interviews revolved around three main questions: What is sustainable development for you? What do you think about the relationship between technology and sustainable development? What are your experiences of teaching technology and sustainable development? A qualitative content analysis is used to analyse the participants' answers. Content analysis is a research method for subjective interpretation of the content of text data through a systematic classification process including coding and identifying themes or/and patterns. During this process, the focus is on the characteristics of language as communication, and on the contextual and content-related meaning produced by the participants (Granheim & Lundman, 2004; Hsieh & Shannon, 2005). The results of such content analysis are conceptualizations or categories that describe the phenomena. The researchers transcribed the interview verbatim and independently read them as whole several times to get to know them, they then met up and compared their analyses. Tentative themes were produced. The didactical questions What, How and Why were used as analyses tools to better understand teachers descriptions of teaching sustainable development in technology. The researchers revisited and reanalysed the data several times and finally came up with three stable themes and categories within these themes. Each theme is described and exemplified by quotes from the teachers. In the result, we only use quotes from seven of eight teachers. The teachers names are anonymous and we use the following fictional names; Ann, Bo, Daria, Cecilia, Eva, Fiona, Gina.

### 4. RESULT

The result show that the teacher's perceptions of sustainable development as part of technology education revolved around three themes: 1) Recycling thinking, 2) Consequence thinking, and 3) System thinking.

*Table 1. Overview of themes and categories*

<b>Recycling thinking</b>	<b>Consequence thinking</b>	<b>System thinking</b>
A) From raw material to recycling	D) Technology impact	G) Life cycle analysis
B) Recycling from a social perspective	E) Technology potentials	H) Material analysis
C) Recycling from a global perspective	F) Ethical dilemmas	I) Technological systems



#### **4.1. Recycling thinking**

The teachers emphasize the importance of students understanding of how a product is manufactured, used and recycled. They regard this as a mean of integrating technologies (objects) and sustainable development by highlighting product development from raw material to finished product, which can then be reused.

Within this theme, there are three categories: A) From raw material to recycling, B) Recycling from a social perspective, C) Recycling from a global perspective

##### *A) From raw material to recycling*

The focus is on a product's life cycle. The teachers who raise this want the students to understand that raw materials are extracted and then manufactured to products and after that recycled. In the excerpt, Ann describes the life cycle of products from raw materials to recycling.

Ann - ... the relation between technology and sustainability has to be like a cradle-to-cradle thought. Therefore, that it is not just the finished product but... it is coming back and will work again as a new product. You can re-use it, it will get into the cycle again.

##### *B) Recycling from a social perspective*

In this category, we interpret it as teachers focus on product development from a broader perspective where humans and social factors are discernible. Humans are, to a greater extent, integrated in the recycling process of product. It is not only the use of products that affect humans but also the extraction and production. Bo describes how recycling of a product can affect peoples in other countries and we interpret it, as he thinks that it is important not to simplify this fact.

Bo - Oh, technology is stuff but it is more than just stuff. It is about where the stuff comes from and how it effects countries and people.[...] an important question is what we do with the trash afterwards. It's so important for us to own things that can simplify for us and then we have to get rid of them... hmm we just put the trash in a black box and send it away for example to Africa. Then people get sick there. I think it is really important that we in technology education point out all this.

##### *C) Recycling from a global perspective*

In this category, teachers focus on earth's resources and emphasize the importance of consumption of raw material and how this affects the entire earth. Sustainable development and technology is in this category viewed as a global matter. Both Ann and Cecilia emphasize the importance of the limited resources on earth.

Ann - Sustainability for me is to work in a way that makes the planet we live on last longer and will be able to feed all... not only some countries, using all the resources. It should be a sustainability for the planet, for all people.

Cecilia -.... farming and utilize our soil and earth in such a way that everyone is well, generation after generation that all people have access to for example water.

#### **4.2. Consequence thinking**

This theme is about teachers' awareness about how and in what ways technology has an environmental impact, both positive and negative. An important part of this is to reflect on consumption of technology and its effects as well as its ethical dilemmas. In this theme, technology is valued in relation to sustainability the character of technology can be judged as good or bad from different perspectives.

There are three categories that describe this theme: D) Technology impact, E) Technology potentials and F) Ethical dilemmas

##### *D) Technology impact*

In this category teachers focus on the use of technology and its consequences for the environment, both through the manufacture of products and their use. The teacher's want to emphasize the way we use technology today, through an accelerated consumption of products. In the excerpt, we interpret it as Daria focus on the financial effects of consumption and Eva on the other hand focus more on ecological and social effects of sustainability.

Daria - Well, the whole financial system is based on the fact that we will consume, produce and buy products. So how to solve that problem, I do not know, but that the way it is. I think this is about sustainable development.

Eva - In one case, I am talking about how you as an individual can influence the environment.... the idea is to talk about how you can act, what you are buying and what you are consuming ... with sustainability in mind. [...] We have to encourage them [pupils] to turn off the light at home, choose another way of transportation, and maybe buy an electric car with more thought of sustainability than previous generations.

#### *E) Technology potentials*

The teachers describe the consequences of technology emphasizing the potentials of using technology to solve environmental problems. In these category teachers shows an optimistic view of technology. They see technology as a possibility to change negative effects on the environment. Fiona points out the negative consequences of technology, but at the same time, she talks about technology as a solution to the environmental problem.

Fiona – Yes, I might have said it before, but I see it as, roughly simplified, that technology has created environmental problems, but technology can also help us to solve the problem. Therefore, the way human use technology really is the problem.

#### *F) Ethical dilemmas*

In this category, ethical aspects are put forward through highlighting personal positions regarding technology and sustainability. We interpret it as the teachers want to discuss the importance of the impact of technology from the perspective that technology can be perceived as right or wrong, good or bad. Fiona describes an awareness about here self as a role model when teaching technology and sustainability another ethical aspect is described in the excerpt from Bo where he describes the importance of problematizing different standpoints.

Fiona - And of course, my way of teaching technology and sustainability depends on my way of being, it is impossible to hide, but I am very careful, it is hard to know what is right and wrong.

Bo -...That we have a good life does not mean that others have it worse but we have to make this clear to the pupils. For example, it is not absolutely necessary to have three cars .... to have this in mind is important when you make decisions.

### **4.3. System thinking**

In this theme, teachers describe how they use a system thinking in their teaching to enable pupils to understand technology as part of a larger whole. The teachers use system thinking in two different ways, as a method to describe technology and sustainability and as a way of understanding technology and sustainability in society.

The theme is described as three categories: G) Lifecycle analysis H) Material analysis and I) Technological systems.

#### *G) Lifecycle analysis*

Under the theme life cycle analysis, teachers describe how they use a product's life cycle in their teaching in technology to show how much a product affects the environment. They say it is necessary to understand all inputs and outputs during the product life cycle from its birth, including design, raw material extraction, material production, sub-production and assembly, through use and final recovery to create an understanding of sustainable development. Both Gina and Eva use this method in their teaching to connect sustainability and technology.

Gina - What I chose to link with sustainable development is when we do a life cycle analysis project. In that project, we follow a product from the cradle to the grave where pupils can see all the steps that are included when creating a product. This means that they find out which raw materials are transported a long way and how the product are recycled.

Eva - You have to do a life cycle analysis, it is on all companies today, so for me it is obvious to explain why I teach life cycle analysis...because you have to have a sustainable thinking when you go through the technology process.

#### *H) Material analysis*

In this category the teachers focus on material analysis to study, on a simplified level and without precise calculations how material, what happens during different processes with the flow of materials in the system. They also connect it with science, e.g. chemistry, when describing a specific material in the production process, as Ann indicate in her quote. We interpret Bo's description, as he wants to create an understanding for the fact that all products consist of material, which has an impact on the environment.

Bo - But it is a lot of focus on materials, even if you look at technological systems, for example to make a wind turbine you still need material to build them, so how do you handle that material. The pupils have thoughts about if you can recycle all materials so that you then can recycle and do one new wind turbine or new products.

Ann - We try to link chemistry and technology, examine different materials and look and see how to use this in technology

#### *I) Technological systems*

The teachers in this category describes how they use large technological systems, energy systems and transport systems, when they integrate sustainability and technology. As we can see in the excerpt from Ann there is a focus on the flow of energy through the technological system. Gina on the other hand focus on components and their function in relation to the whole.

Ann - We focus on technical systems. We have chosen to work with electricity and energy systems. There is a lot of energy that disappears along the way and what to do about that, to get a sustainable thinking? How to do when using energy, different kinds of energy. So, I think it is advisable to connect sustainability and technological systems.

Gina - In grade 6, we look at a technological system in relation to electricity in the city. What happens if you remove components, so that they understand how everything is connected. In grade 9 we investigate, technological systems but then focus on electronics.

## **5. DISCUSSION**

In line with earlier research (Elshof, 2003; Stables, 2009) about technology teachers' teaching of sustainable development the result in this study confirm that teachers often connect sustainable development and technology to the ecological design of products, as we can see in the category A), G) and H). However, we also see a clear connection to social and cultural aspects of sustainability in the theme Consequence thinking and System thinking.

In the theme Consequence thinking, the teacher Fiona, in line with Pavlovas (2006) and Elshofs (2005) research, describes that her own perceptions on sustainability affects her teaching and that she considers it important for teachers to be aware of this. In this theme, the teachers also describe the importance of pupils' reflection concerning effects of technology in today society.

The teachers in this study confirm the optimistic view of technology that Knutsson (2018) and Elshof (2009) highlighted in their studies, see Fionas excerpt in category E). A critical approach to technology and sustainable development is not visible in these research interviews, which indicates that there is a need of more knowledge among technology teachers about this.

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# What technology content and values emerge in the teaching of climate change?

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Today, many people live with climate anxiety, and both politicians and companies emphasize how important sustainable strategies and activities are for developing a society with less impact on climate change. Within education, it is central to implement themes dealing with such issues as well. As a technology teacher, one will be expected to have knowledge and ideas about teaching the climate issue, and to be prepared to manage climate anxiety among students. With the aim of supporting teachers, a group of climate researchers, professional teachers, and pedagogues from a science centre, have cooperated in developing a Climate Kit, including an instruction sequence, and teaching materials. This climate kit will be used in primary and secondary schools during 2018. When the kit will be (1) developed, (2) tested and (3) implemented to teachers within a course and (4) used in classrooms, a research study will be accomplished as well. Empirical data in this present study emerge from observations of (1) workshops with the actors when the kit is created and (2) tested in classroom as well. The observations will thereafter be analysed using a discursive perspective partly with aim to identify what knowledge content in relation to climate change that is highlighted in the technology teaching, and partly with a discourse analytical perspective focusing on the values and steering strategies within the teaching practice. The research question: What content, values, and strategies concerning technology and climate change emerge as important? The aim of the study is to investigate teaching content and teaching approaches within technology education, focusing on climate change, with an overall aim to analyse and describe technology education for social and environmental change. This paper presents the results emerging from analyses of empirical data, see above, from workshops and test of the climate kit. Both the collecting of empirical data and the analyses was completed during March 2018.

*Key Words: technology education, climate change, discourse analysis.*

## 1. INTRODUCTION

At the Paris climate conference (COP21) in December 2015, 195 countries agreed to a global action plan to limit the global warming. The success of COP21 rests on knowledge and awareness about our changing climate. Knowledge and awareness establish in school. The syllabus for the technology subject in Sweden contains goals for developing knowledge about the impacts of technology on the environment, society and human beings. Technology education should also make young people aware of the consequences of their own choices and equip them with skills, knowledge and dispositions to understand and make evidence-based decisions about both personal and global issues. In Sweden, and other countries, underlying science on these issues has been taught regularly in school (for example energy sources and greenhouse effect). However, linking to the global and controversial nature of climate change and the relationship with technology is rarely seen. Today, many young people live in fear of climate change. This generates a sense of hopelessness about our future, which undermines motivation to work towards a better future by taken positive action to limit climate change. Teachers must have the opportunity to extend their knowledge about the climate (Bryce & Day, 2014) and about argumentation in science and technology classroom (Martín-Gómez & Erduran, 2018). As a support to teachers, some actors (climate researchers, in-service teachers, and pedagogues from a science centre) have the intention to develop a climate-kit that will help teachers make knowledge about climate more accessible to their pupils. The aim with that project is to create fact-based optimism among teachers and pupils. Scientists work together with pedagogues to design a professional development course and teaching kits. In-service teachers will ensure that the climate-kit is useful for the target group. In total 120 practicing teachers will participate in the course. The course would result in skills related to the climate kit and knowledge about

climate change. After completion of the course, all participants will receive the kit for implantation in their own practice.

This present study will investigate technology teaching within the project, described above. In this paper, phase one of the study is presented; investigation of the development and tests of the climate kit. The course and implementation in classes will be investigated in phase two of the study, during autumn 2018. The aim with the study in total is to investigate the teaching content and teaching approaches related to technology education with the focus on climate change, emerging in the project. With an overall aim to analyse and describe technology education for environmental and social change. This is an example of future educational challenges from a technology perspective. Chang & Pascua (2017) argue; “given the complexities and uncertainties of a climate changing world, children who are unable to engage climate change issues will likely miss the benefits of CCE (climate change education). Hence, it is the /.../ educators’ job to continue working on research that will impact the way the topic is taught and learned, with a view to helping children succeed in a climate changing world” (p.179).

## 2. LITERATURE REVIEW

The herein presented case study focus on teaching content, and what attitudes and values that follow the content imbedded in the teaching when the climate-kit is used. Science and technology education researchers have argued that socioscientific issues ought to be used as contexts for learning (for example Sadler and Dawson, 2012). In particular, climate education must allow children to engage in climate change discourse, critically and accurately. Climate change is characterized by complexity and uncertainty, and schools need to teach the issue of the latest climate change, especially global warming, to equip students to mitigate and adapt to the expected global conditions. Such education is believed to be the most important strategy for building climate knowledge (Kagawa & Selby, 2012). When deciding on, and arguing about climate change issues, individuals may need more than scientific evidence. They may need to identify and analyse social, economic, ethical or political aspects and claiming that recognition of the complexity of the problem and investigating the issue from multiple perspectives are important aspects of decision-making (Sadler et al., 2007). Some studies have investigated explicitly climate change education (Bravo-Torija and Jiménez-Aleixandre 2012; Klosterman and Sadler, 2010). There occur a teacher-led classroom education where technology cases or dilemmas are included within a science topic (Klosterman and Sadler 2010). The teaching may include explicit argumentation and conceptual understanding. The approach to inclusion of social scientific issues, for example climate change, in classroom is varied but research supports the imperative role of the teacher in the success of the intended outcomes (Marin & Halpern, 2011).

Within technology and science education, earlier research finds specific subject content that promotes action competence for the future among the adolescents. Action competence is considered as being related to confidence in one’s own influence, knowledge of action possibilities, and a willingness to act (Breiting & Mogensen, 1999). However, research shows how education on climate change usually will face low-impact actions, hoping to cause individuals to change behaviour later in life (Thøgersen and Crompton, 2009). Wynes and Nicholas (2017) have identified four recommended high-impact actions to highlight, which they believe to be especially effective in reducing an individual’s greenhouse gas emissions: having one fewer child, living car-free, avoiding travel with aeroplane, and eating a plant-based diet. When Wynes and Nicholas (2017) analyses educational texts, they show that education books embraces more of naïve examples and do not focus on high-impact actions and controversial issues. Wynes and Nicholas want to emphasise that education creating a limiting gap between educational content and individuals willing to align their behaviour with climate targets. Their results show the important role of more high-impact aspects in education and they argue, “high-impact actions (through providing accurate guidance and information, especially to ‘catalytic’ individuals such as adolescents) could be an important dimension of scaling bottom-up action” (p. 7).

### *Theoretical frame*

The present study arise the research question; *what content, values, and strategies concerning technology and climate change emerge as important?*

The analyses are based both on identifying what knowledge content in relation to technology that is occurred in the climate kit, and somewhat a discourse analytical perspective (Gee, 2014) focusing on the values and governance strategies within the climate kit (Öhman, 2010). The theoretical frame of the study is inspired by the notion of "big D" (Gee, 1990); "Discourses are ways of being in the world, or forms of life which integrate words, acts, values, beliefs, attitudes, social identities, as well as gestures, glances, body positions and clothes" (s. 142). Inspiration from Öhman (2010) as well, and her arguments about school subject's practices and the relation to power. Öhman (2010): "A school subject's practices, traditions and customs are often deeply rooted in the teaching practice, and often regard content as natural and obvious. With the aid of [a Foucauldian power perspective], it becomes possible to study how the knowledge, norms and values included in an activity render certain ways of acting more reasonable and others less reasonable and thereby benefit certain ways of acting and being" (p. 406).

### **3. METHODOLOGY**

Results to be presented in June 2018, at the PATT-conference (Pupils attitude towards technology) will be obtained through: (1) observations of workshops with actors developing the climate kit and (2) observation of test teaching sequences in a classroom. Actors that develop the kit are climate scientists, science centre's pedagogues and primary school teachers. When tested in the classroom, one climate scientist and two science centre pedagogues were teaching. Observations of workshops and classroom tests were made, and those sessions were audio recorded and transcribed as well. The aim of the study in total is to investigate teaching content and teaching approaches within technology education. Further, what values and governance strategies that emerge. All these aspects will be searched for within the workshops and test teaching practice. The observation notes and transcripts were analysed in an iteratively process with aim to generate empirical data about the subject content, values and steering strategies.

### **4. RESULTS**

#### ***4.1. Workshops for to develop the climate kit***

From observations of workshops, the first results that emerge from analyses show how the different actors (scientists, pedagogues, and teachers) communicate content and signal values. Climate scientists communicate basic concepts that underlie our current climate understanding. They argue to motivate with knowledge and a sense of hope for our individual and joint efforts to combat climate change. First of all, knowledge about the greenhouse effect and the role of carbon dioxide. They also highlight that a series of natural feedback mechanisms regulate the climate. Climate feedback can be negative or positive. Albedo (referring to the Earth's ability to reflect solar energy back into space) is an example of a positive feedback. Snow and ice have high albedo and reflect solar energy back into space. If there is less snow and ice, the earth's albedo reduces, less solar energy reflects in space, and the earth gets even warmer. Climate scientists stress the importance of the knowledge about the greenhouse effect and albedo. In addition, our contribution to climate change must be seen in the context of natural feedback mechanisms. In addition, daily efforts from individuals to mitigate climate change, based on knowledge about the climate system, are important. The scientists emphasize actual knowledge as a fundamental reason for understanding how technology activities (human activities) will interfere with the climate. They claim that knowledge primarily develop through inquiry-based experiments.

The science centre's pedagogues communicate how the technology activities affects the climate. They have developed educational themes about food, clothing, transports and use of technology in household with the aim of challenging students' understanding of aspects that interfere with the greenhouse effect. Focus is the amount of carbon dioxide contributed in the activity. The activity aims to force students to choose and to value, be a "good or bad" climate person and appreciate the possibility of using less carbon dioxide. The important content is the amount of carbon dioxide produced in various technical systems, processes, materials and agricultural methods. In addition, the students will have to evaluate and argue.

The in-service teachers communicate how important it is that the students think that the activities and the experiments are fun and interesting. They also want the students to use digital tools when they work with themes, activities and experiments.

#### 4.2. The test sequence

The climate kit test can be described consisting of two parts. Part 1 – investigation of carbon dioxide (CO<sub>2</sub>) and the relation to a higher temperature. The climate scientist (CS) was guiding two one-hour lessons, a group of 20 pupils with age 10, each hour. In total 40 pupils. They were sitting around two tables and expected to make an experiment. At one table they had a source of CO<sub>2</sub> (with C-vitamin tablets), figure 1, and at the other table there were no CO<sub>2</sub> source, figure 2, otherwise the same condition apply at the two tables. The CS was initiating with questions about CO<sub>2</sub> and a relation to a warmer climate. CS was focusing very clearly on one issue; can we see it with our own eyes, how CO<sub>2</sub> makes it warmer? Thereafter CS introduced the experiment. When the experiment was completed, CS summarized and concluded in a statement about how CO<sub>2</sub> make the climate warmer. After that, CS was arguing for that individuals have to produce less CO<sub>2</sub>, thereby leading into Part 2.



Figure 1 and 2. One lamp (the sun), one glass jar with lid (greenhouse), a thermometer fixed in a small globe (the earth). To the left, pink fluid (c-vitamin (CO<sub>2</sub>)) and water, to the right only water. Two comparative experiments that were continuing at the same time.

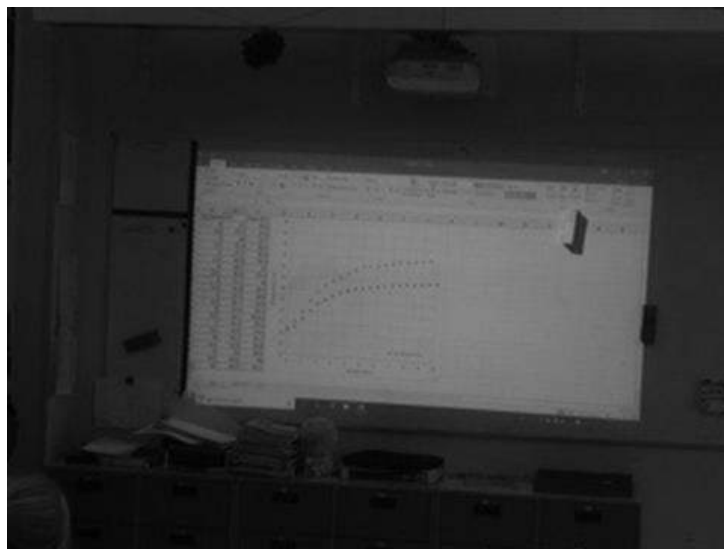


Figure 3. When the pupils were reading the temperature every 30 second during 10 minutes, CS wrote the amounts into the computer and two different curves appeared on the screen. The pupils could see how the temperature in the CO<sub>2</sub>-glass jar was increasing to a higher level.



Part 2 – two science centre pedagogues were guiding the same pupils as in part 1, in a four stations activity during one and a half hour (each group of 20 pupils). Five pupils in each subgroup rotated between these four activities:

- Activity 1) How far could you travel when using 1 kg CO<sub>2</sub>? With an aeroplane, a car, a train, a bus, a bike, a sailing boat? (six distance scenarios were given, places from real life, a picture of a map were included) the pupils were expected to rank the vehicles in order from shortest distance to longest, discuss, come up with arguments and write everything down. See figure 4.
- Activity 2) How much CO<sub>2</sub>, common household technology contribute with when being used? Make a ranking between; 15 minutes of a warm shower, one-hour use of an oven, one hour TV, one hour using an iPad, one search with google, one text message. The pupils were expected to rank, discuss, argue and write their answer down.
- Activity 3) to choose food and be a “good or bad” CO<sub>2</sub>-contributer! Choose from pictures of food (salad, tomatoes, potatoes, rice, meet, pork, chicken, fish, beans, root vegetables etc.) and then pick up CO<sub>2</sub>-weights for each specific food-piece (weights were marked with name of the food stuff and designed in a size proportional to CO<sub>2</sub>-contribution), then use a food scale to get a total CO<sub>2</sub>-weight for the whole meal. The pupils were expected to argue, explain, make their own choice and discuss and write their answers down. See figure 5.
- Activity 4) about the use of clothes. Be a “good or bad” CO<sub>2</sub>- contributor! When buying clothes? In a luxury boutique, in a cheaper boutique, in a shop with only ecological clothes, in a vintage/second hand shop or if you change clothes with a friend? The pupils were expected to argue, discuss, explain, and make their own well-founded choices. See figure 6.



Figure 4. Activity 1.

Figure 5. Activity 3.

Figure 6. Activity 4.

In part 1 the CS guide the pupils to evolve a knowledge content, not mainly technology content rather natural science content. With well-planned open questions, specific and exact aims, they will make the experiments, and thereby be trained in inquiry-working routines and principles. The CS has a clear focus on the specific issue as well: we must see, with our own eyes, if CO<sub>2</sub> contribute to a higher temperature. In this context, it seem to be important to be convinced about the fact of greenhouse effect. The subject content that emerge are inquiry-work skills and the knowledge that CO<sub>2</sub> make the temperature rise. The CS makes connections to the own profession as a researcher, how exciting it is and how important the researcher is for making evidence undoubtedly and statements truthful. Great valuing of scientific knowledge arises, thereby highlighting the role of research in searching for convincing truth. Many of the pupils seem to follow the CS’s guiding and the very plain instructions. Some pupils answer on questions very ingeniously and many seem to get an interest for inquiry. Nevertheless, it seems to be a lack of similarities between different pupils pre-knowledge, and to what extent they can follow and participate in the discussions.

In part 2, it emerge a lot of specific technology subject content. The pedagogues highlight content such as:

- There are most contributions of CO<sub>2</sub> in transport systems and in food processing
- A strategy to find out CO<sub>2</sub> contribution could start with analyse of energy usage
- Knowledge about energy sources and amount of energy usage are relevant. How the electricity is produced, what kind of fuel and technique
- Knowledge about the systems function seem to be necessary as well, for example differences between a google search and a text message, about the use of internet (electricity usage) or the mobile network (less electricity)

Therefore, knowledge about energy systems, energy sources, energy usage, are important content for understanding the CO<sub>2</sub>-contribution. In addition, material production, the origin of different materials and energy usage for recycling compared with new production. Food processes comprises agriculture, animal farming (including the aspect of cattle and their methane production), breeding and transport systems as well. This make the CO<sub>2</sub>-production very complex and very focused on system understanding and especially about energy.

The pedagogues had to guide the pupils in every activity. The tasks seem to be rather difficult to grasp, it requires an understanding of the complexity, a broad holistic view and a deep understanding of some technology systems. However, in this session it became very clear for the pupils that individuals have to contribute with less CO<sub>2</sub> and they seem to understand how to do it, the challenge is how to argue, when deep and specific knowledge is required. Some of the pupils have a well-developed understanding of all these aspects, they refer to attitudes and habits in their own families, for example; eating vegan food, avoiding car-transport, buying clothes at second hand, showing pride of their impact. Other pupils also refer to personal experiences but emphasize a more worried approach. They ask if their long travel habits is a problem. In this session, it will become very clear for pupils that there is a distinction between being a “good” and “bad” climate individual.

## 5. DISCUSSION

During the observations of the climate kit developing workshops, there are divergent aims and views between climate scientists, science centre pedagogues and primary school teachers. When it comes to important subject content and how to use the climate kit, with a technology perspective. The high valuing of fact knowledge (greenhouse effect and albedo effect), and how that will become understandable for pupils through experimental work are views encouraged by climate scientists with a great power and scientific status. The science centre’s pedagogues focus more on activities with “high-impact” (Wynes & Nicholas, 2017), and seem willing to point out the quantity of CO<sub>2</sub>-contribution in relation to technology as important knowledge. They focus on pupils own choices as well and argue enthusiastically for sustainability and individual action competence. The professional teachers do not seem to have entrance to establishing the subject content or the teaching methods, and they take an inhibited position. The specific content occur in consensus, with different actors taking different views. The attitudes and roles present, shows a hierarchic structure with differences between scientific status and teacher status.

During the observations of the test sessions, the climate scientists could transform their intentions and aims within the teaching situation. A clear focus on one defined issue, and highlighting the relevance and the importance with inquiry-work, seem to give expected result. The climate scientists take advantage of the researcher role and could thereby guide the pupils with authority. For the pupils, the researcher role and the inquiry-work are something familiar. They could recognize the procedures for the lesson but also imagine the special conditions that are available this day.

During part 2, when more of technology content was taught, the complexity and the diversity in the technology subject emerged. The intention with the sequence seemed to be that pupils were expected to view and reflect over “high impact” aspects, and therefore the pupils met four different technology areas with great impact on CO<sub>2</sub>-contribution. It seem to be possible, in a normative way, to explain how humans have to act and what decisions one should take. However, it seem more complicated and more time consuming to develop pupils knowledge for understanding the complexity and underlying aspects, and thereby realize and really understand

choices and action strategies. Knowledge content emerge during the session, but the normative intentions to influence behaviour appear to be more important.

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# Technological Thinking by Children with Special Needs

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Special education interventions involve methodical instruction, teaching, and therapy activities specially developed for children with special needs. Some children referred for special education at younger ages are defined as having developmental delays. Methods commonly in use focus on series of tasks and exercises of generic character, many times detached from relevant contents and contexts for the child. Many studies have shown that critical skills for academic learning can be promoted at young ages, but studies focusing in special education children are scarce. This study focused on the influence of technological thinking tasks on the advancement and improvement of children-with-special-needs' executive functions, problem-solving abilities, and motor and graphomotor skills. During the study, children were exposed to content-rich and context-relevant tasks encouraging design and building processes, problem-solving, and planning and documentation activities. The results of the study indicate a significant improvement in all the functional skills observed: fine motor skills, executive functions (e.g., attentional control, inhibitory control, process control), and problem-solving skills. The intervention implemented in this study follows the assumption that technological thinking might help achieve many therapeutic and learning goals for special education children. The main innovation in the study is the evidence collected on the clear effect of technological thinking tasks on the advancement and improvement of the target skills.

*Key Words: Technological thinking, Special education, Problem solving, Design and building, Executive functions.*

## 1. INTRODUCTION

Special education is concerned with methodical teaching, learning, and therapy interventions for children with special needs.

Children accepted to special education pre-schools, characterized as children with delayed development, are mostly children with multiple problems, with recognizable delayed development in most areas of functioning. Any attempts to characterize these children using one diagnostic label are doomed to failure due to their great heterogeneity. Children are characterized and diagnosed by the gamut of their particular problems in the various areas of development: gross and fine motor skills, speech and language, cognition, social/ personal, and ADL - Activity of Daily Living. (Shevell, 2010).

The quality of educational interventions at preschool age and how these are adapted to each individual student has considerable influence on developing children's capabilities in general and preparing them for study at school in particular (Barnett, 2002). Children in special education need, more than anyone, programs that impart knowledge and develop cognitive and performance skills aiming to support their independent learning in the future. Children with learning disabilities are unsuccessful in developing their own effective learning styles. For this purpose, curricula and teaching methods are created aiming to enable good preparation for school (Rimm-Kaufman, Pianta, & Cox, 2000; Heckman, Stixrud, & Urzua, 2006).

Executive functions and fine motor skills are important skills required for academic achievement in school (Cameron et al., 2012; Diamond 2012; Duncan et al., 2007; Grissmer, Grimm, Aiyer, Murrain, & Steele, 2010; Mazzocco & Kovner, 2007; Morisson et al., 2010). It was indeed found that children with the poorest executive

functions benefited most from intervention programs aimed to advance the acquisition of crucial skills (Flook et al., 2010; Karbach & Kray, 2009; Lakes & Hoyt, 2004). Diamond and Ling (2016) found that executive functions (a set of cognitive processes that are necessary for the cognitive control of behavior, e.g., attentional control, inhibitory control, process control) must be challenged consistently, and practice and training can lead to improvement.

It was found that technological tasks enable children to develop fine motor skills, hand-eye coordination, problem solving ability, and even acquire social skills. Moreover, this type of activity is enjoyable and leads to motivation (Bers, Flannery, Kazakoff, & Sullivan, 2014). Technological thinking arouses curiosity, requires higher order thinking, analytical skills, abstraction, and problem solving, and enables processes of knowledge construction and learning. Technological curricula suitable also for young children have recently been developed (Barron et al., 2011). Bers (2008) saw that construction and design processes support learning and the development of technological reasoning skills

In our study, we hypothesize that the acquisition and practice of technological reasoning skills can contribute to advancing and developing learning skills that are difficult for children with developmental delays (Thomas, 2016) like fine motor skills, graphomotor skills, executive functions and cognitive flexibility.

### ***1.1 Research rationale***

The study examined the effect of (1) technological thinking and (2) the involvement in planning, constructing and documenting on reasoning skills development by children with developmental delays in special education preschools.

The research questions were defined to examine the following topics:

- The effect of the exposure to various construction sets and building tasks, on planning and fine motor skills.
- The effect of documenting the built models on children's graphomotor skills.
- The effect of exposure to planning and building tasks using various construction sets on organizing thinking, executive functions, and ability to cope with and solve problems.

## **2. METHODOLOGY**

### ***2.1 Population***

The research is a qualitative study that followed ten preschool children, aged 5-6, who had been diagnosed with a developmental delay by a developmental pediatrician and attend a special education kindergarten.

The main characteristics of children's difficulties in preschool are language delays, sensorimotor problems – difficulties in the maturity of the sensory systems, gross and fine motor skill functions, graphomotor performance, and visual perception, organizing thinking and executive functions. Likewise, social-communication difficulties, low frustration threshold, and motivational difficulties. (Shevell, 2010; Thomas, 2016)

An intervention program was created built on exposure to technological thinking tasks, and based on the acquisition, development, and organization of thinking skills, alongside developing language, motor, and social-communication skills. It was designed on the basis of a long-term research plan carried out in regular experimental kindergartens (Kuperman & Mioduser, 2012).

Unlike other children, children with developmental delays require mediation, focus, direction, and learning the strategies essential for life in general and learning in particular. The ability of early intervention programs to minimize declines in development has been reported (Guralnick, 1991). As well, technological thinking tasks might serve as effective tool for achieving many therapeutic goals for children in special education (Kuperman & Mioduser, 2012).

The intervention program focused on a wide range of skills: communication and interaction among children, fostering language skills; organization skills in both free and structured task planning and execution; motor skills (e.g., experiencing the body in a space, planning, directionality); fine motor skills (e.g., work with construction sets that require motor and visual perception accuracy); graphomotor and visuomotor skills required for the documentation of the constructed models; bolstering self-image and a sense of efficacy; problem solving – including experiencing defining the problem, raising possible solutions, selecting and implementing the solution, and then re-examining the situation.

The intervention program included a range of components. In this paper we chose to focus on four main areas: Fine motor and graphomotor skills, reasoning skills, executive functions and problem solving.

## 2.2 Data collection

For gathering the data, the experiences were documented through observations, documentation and photocopying of children's products and construction processes. The learning sessions as part in the intervention program were conducted by the teacher under the guidance of the researcher following prior training. The intervention program was conducted in the kindergarten as part of the regular activities. In addition, individual meetings were held with the children following construction and documentation tasks

Data collection was conducted during eight sessions throughout the school year and focused on three aspects of children's performance: Construction, graphic documentation and problem solving.

**Construction** – The tasks involved the use of a range of construction kits - the children were asked to build a model of their own free choice, to give meaning to the model we used to explain its uses. The observations focused on hand-eye coordination ability, motor accuracy ability, strength regulation, and hand manipulation ability (Figure 1).

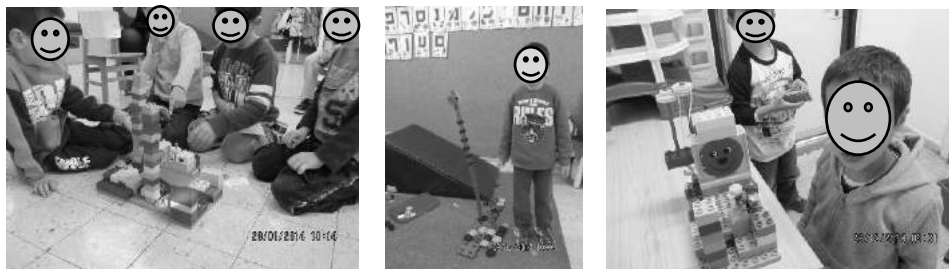


Figure 1: construction tasks

**Graphic documentation.** After completing the construction, the children were asked to document their creations. The observations focused on hand-eye coordination, visuomotor skills, and ability to plan in a graphic setting. As well as on Pencil control and graphic accuracy and ability to represent, e.g., representation of color, shape, a moving element (Figure 2).

**Problem solving** - the children were asked to build a path in space using cones and cubes, before or during the construction they were presented with a problem they must solve. Children experienced situations in which they were required to identify a problem, define it, plan a solution, and carry it out. During the day, even beyond the technological tasks, the children were expected to plan and carry out problem solving process linked to the kindergarten's daily activities (Figure 3).



Figure 2: documentation tasks

Figure 3: documentation tasks

A graded scale was constructed according to the level of performance. The levels were defined in values 0-3 in a multilevel form where 0 describes incompetence and 3 describes an age-appropriate ability.

### 2.3 Research variables

#### 2.3.1 Independent variables:

The independent variables were the technological thinking tasks administrated during the intervention: Construction, documentation, and problem-solving tasks.

#### 2.3.2 Dependent variables

- Fine motor skills – hand-eye coordination, strength regulation, fine motor accuracy and control, in-hand manipulation ability.
- Graphomotor skills – pencil grip, line quality, and use of line complexity
- Thinking and executive functions – organizational and planning abilities for construction tasks – choosing the parts, matching them, ability to solve problems during construction, and providing significance, planning ability during construction, checking ability during the process, and flexibility of thinking.
- Problem solving – ability to identify and define a problem, raising possible solutions, choosing, implementation, and checking.

## 3. RESEARCH FINDINGS

The figures below describe group and individual progress during the study at eight assessment points, by the dependent variables examined. The findings are presented according to the research questions.

### 3.1 First research question: *Does experiencing with technological thinking tasks affect the development of fine motor, graphomotor, executive functions and problem-solving skills, by children with special needs?*

A significant improvement can be seen in the mean performance of the group for the fine motor skills hand-eye coordination, strength regulation, motor accuracy and control, and in-hand manipulation (Figure 4) The score at the beginning of the year ranged from 0.5-1 and reached 2.3-2.8 at the end of the year.

Significant progress can be seen concerning thinking skills and executive functions (e.g., planning, process control capability, attention, importance and control, see Figure 5). The score at the beginning of the year ranged from 0.2 to 0.7, and at the end of the program it reached 2.6-2.8.



Figure 4: Group progress in fine motor skills along construction tasks

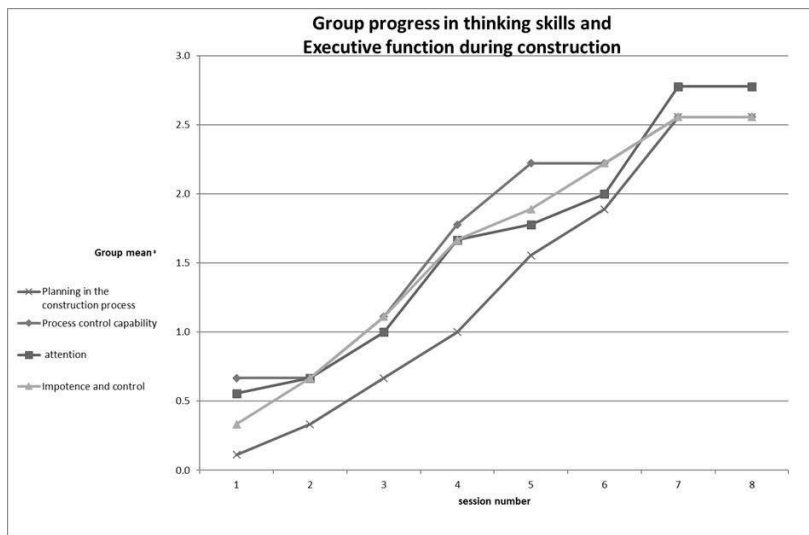


Figure 5: Group progress in thinking skills and executive functions along construction tasks

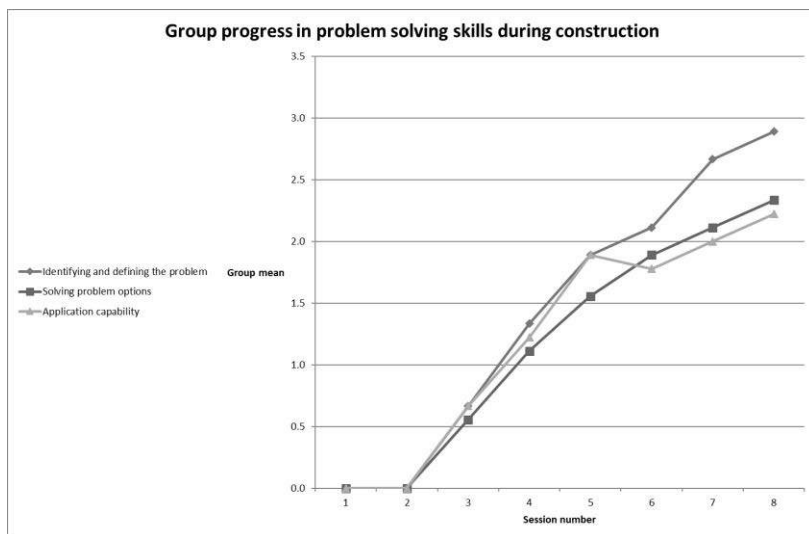


Figure 6: Group progress in problem solving skills along construction tasks



It can be seen that children began with extremely low level of problem solving capability, and there is clear progress along the construction tasks in ability to identify and define the problem and raise and implement possible solutions. Graph 6 presents the capabilities to identify a problem, the ability to raise options for solution and the ability to implement a solution. At the beginning of the year the children showed an inability to solve problems and received a score of 0, at the end of the year received a score between 1.8 and 2.6.

Concerning graphomotor skills in documentation tasks, significant improvement can be seen for sub-variables such as pencil grip, line quality, use of complex lines, thinking about correct use of page space, size, and presentation (Figures 7 and 8). At the beginning of the year they scored between 0.3-0.6 and at the end of the year they reached the intelligence level 2.3-2.7.

Similar progression has been observed along the tasks for problem solving skills. In Figure 9 the group results for the different sub-skills show a clear progression along the tasks. In Figure 10 the values for the individual children is shown, indicating a clear progression as well.

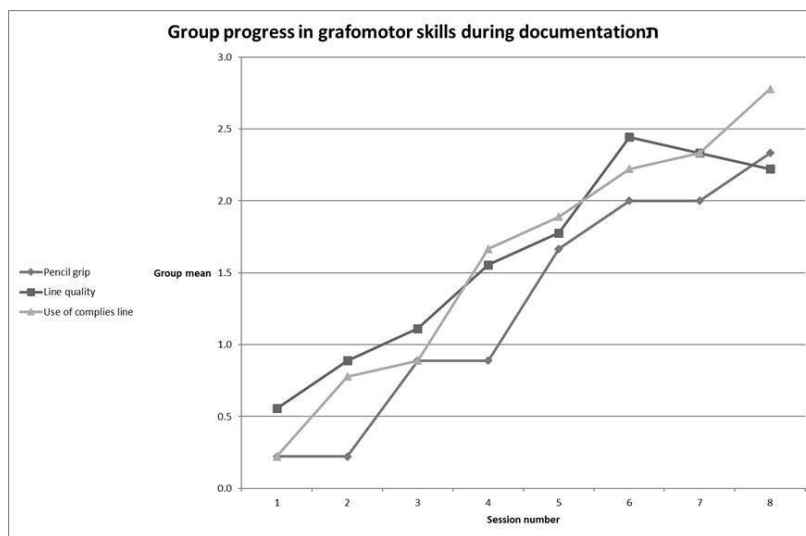


Figure 7: Group progress in graphomotor skills along documentation tasks

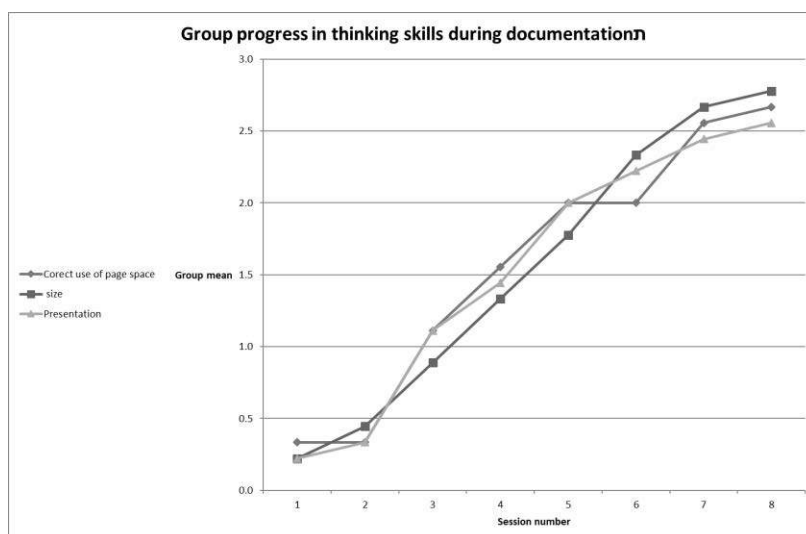


Figure 8: Group progress in thinking skills along documentation tasks

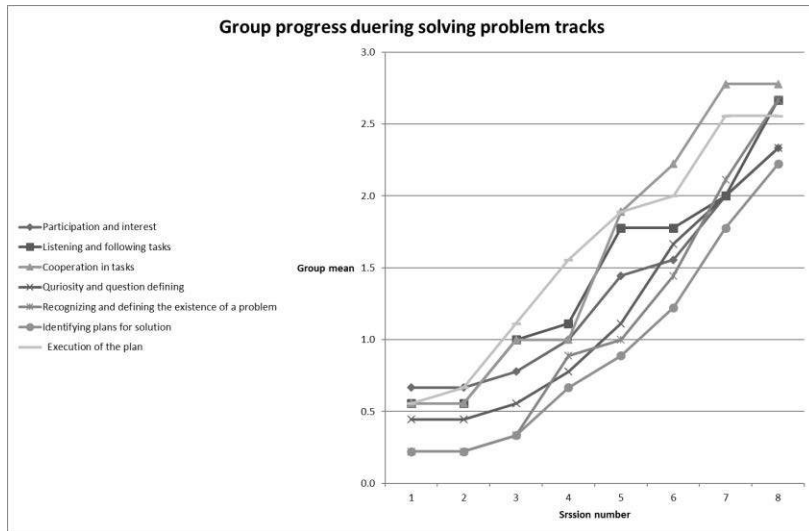


Figure 9: Group progress along problem solving tasks

**3.2 Second research question: What characterizes individual children’s development of performance and reasoning skills as a function of their involvement in technological thinking tasks - construction, documentation, and problem solving tasks?**

The graphs below describe the progress of each child in each field (fine motor graphomotor and problem solving). The progression is described according to the mean scores on the 8 test points.

In Figures 10, 11, and 12 the individual children’s means in the construction tasks are presented. The data indicates that all children gained significant progress in fine motor skills, executive functions, and problem-solving abilities along the construction tasks.

The group in the special education kindergarten is obviously heterogeneous. Every child has difficulties of varying degrees in different areas and this is evident in children’s performance as observed in the first assessment point of motor skills. Along the construction tasks two sub-groups have consolidated, showing clear gap in performance between them. However, all children in both subgroups gained clearly from the intervention as it is evident in the graphs depicted in Figure 10.



Figure 10: Progress of individual children in fine motor skills along construction tasks

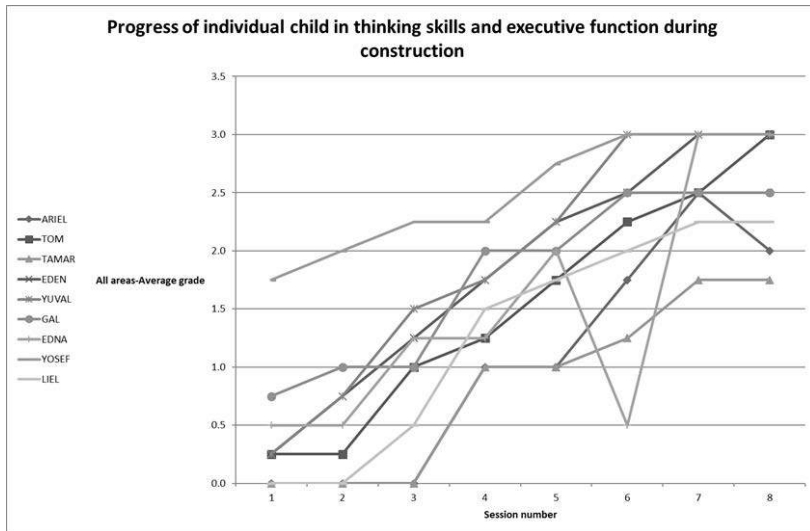


Figure 11: Progress of individual children in thinking skills and executive functions along construction tasks

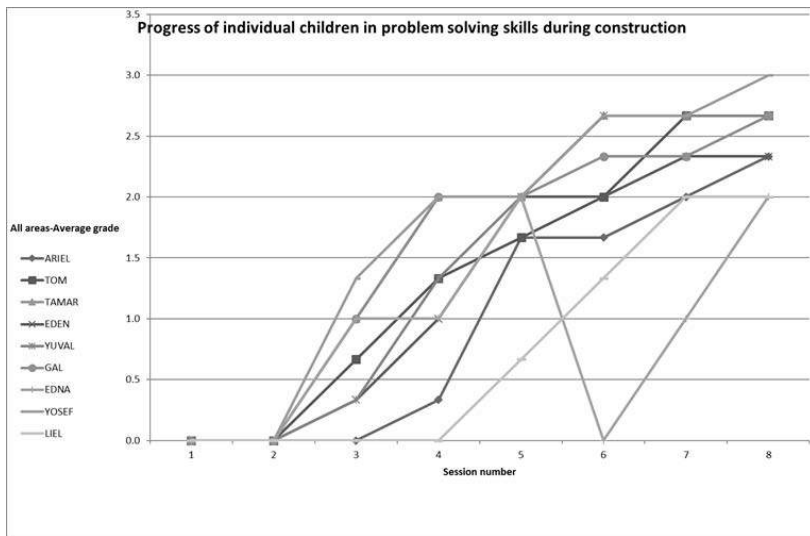


Figure 12: Progress of individual children in problem solving skills along construction tasks

For thinking skills and executive functions (Figure 11) and problem-solving skills (Figure 12) in construction tasks, as well as for performance and thinking skills in documentation tasks (Figures 13, 14) the data shows similar trends, in which progress in skills acquisition and performance is evident along the assessment points.

Figure 15 relates to children's individual progress in problem solving tasks. The overall pattern along tasks and assessment points is similar to that observed for all previous skills in construction and documentation tasks. In problem solving tasks, all children but one showed consistent progress along the assessment points in quite homogeneous path. Yosef outperformed exceptionally in comparison with the other children from the first assessment point, showing high level performance along the tasks. We will refer to Yosef's case in the next section.

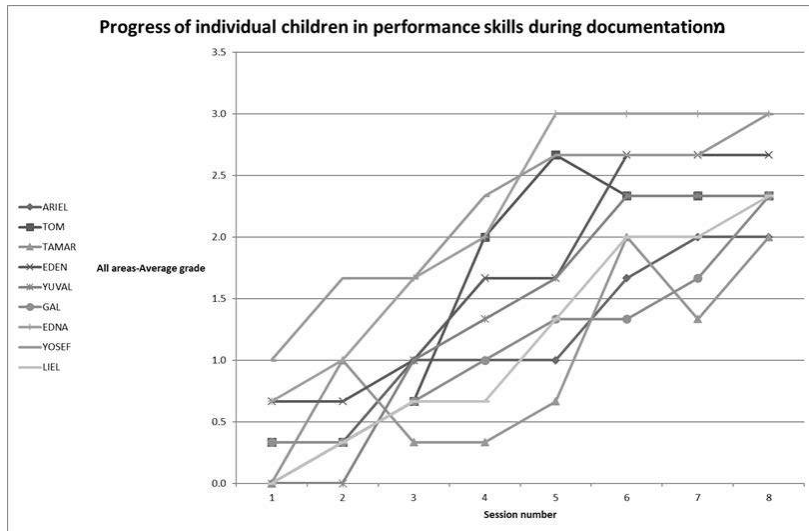


Figure 13: Progress of individual children in performance skills along documentation tasks

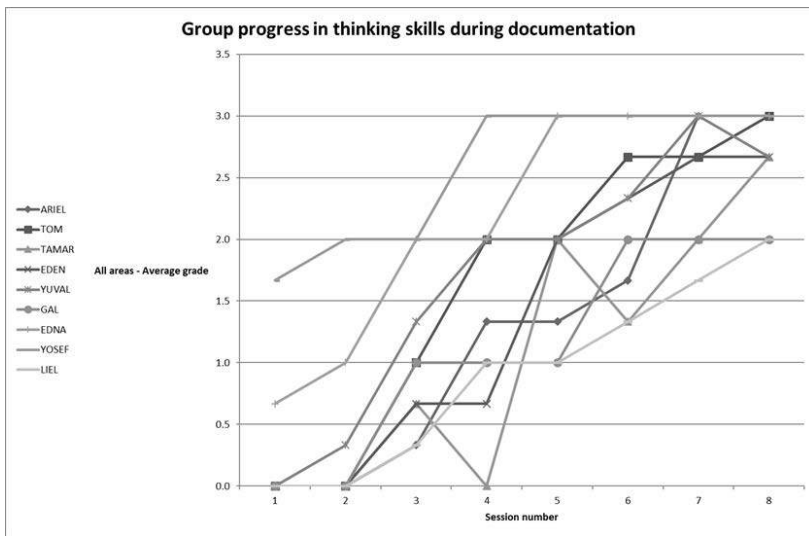


Figure 14: Progress of individual children in thinking skills along documentation tasks

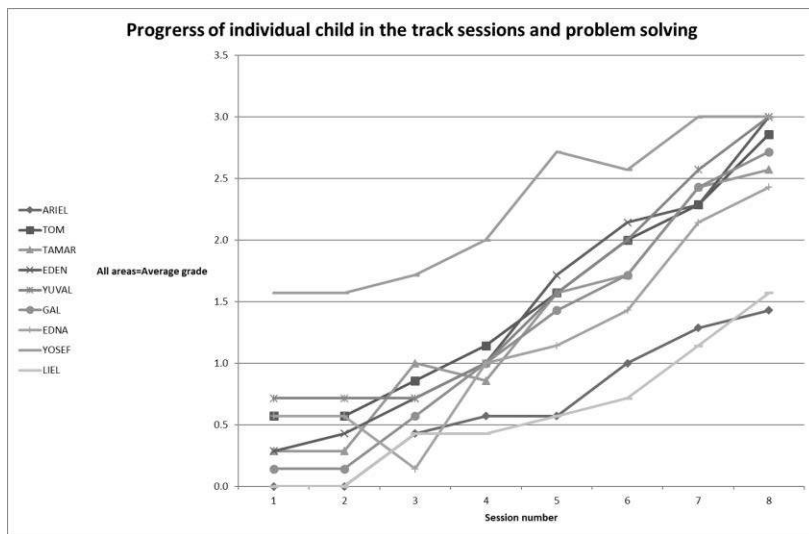


Figure 15: Individual progress along problem solving tasks

**3.3 Third research question: Which children will be helped most by the technological thinking tasks?**

To answer this question, we examined which children made the greatest progress and every child's performance and difficulties in the various skills. In the following two sample cases are presented (Figs. 16,17).

Yosef is a boy who came to the kindergarten with a diagnosis of difficulties in gross, fine motor, graphomotor and problem-solving capabilities, in organization and planning both in space and in thinking tasks and a poor self-image. However, he was clearly motivated and had perseverance abilities. We already observed significant progress at the beginning of the sessions. He showed high-level abilities relative to the other children.

Gal moved to the special education preschool after failing to integrate in a regular preschool. No difficulty was observed regarding gross motor skills, but he had difficulties in fine motor skills, language, organization and executive functions, sensory processing, and graphomotor abilities. His performance level corresponded to the age-level of a two-year-old. He was poorly motivated and avoided trying. He had conflicts with the staff and children.

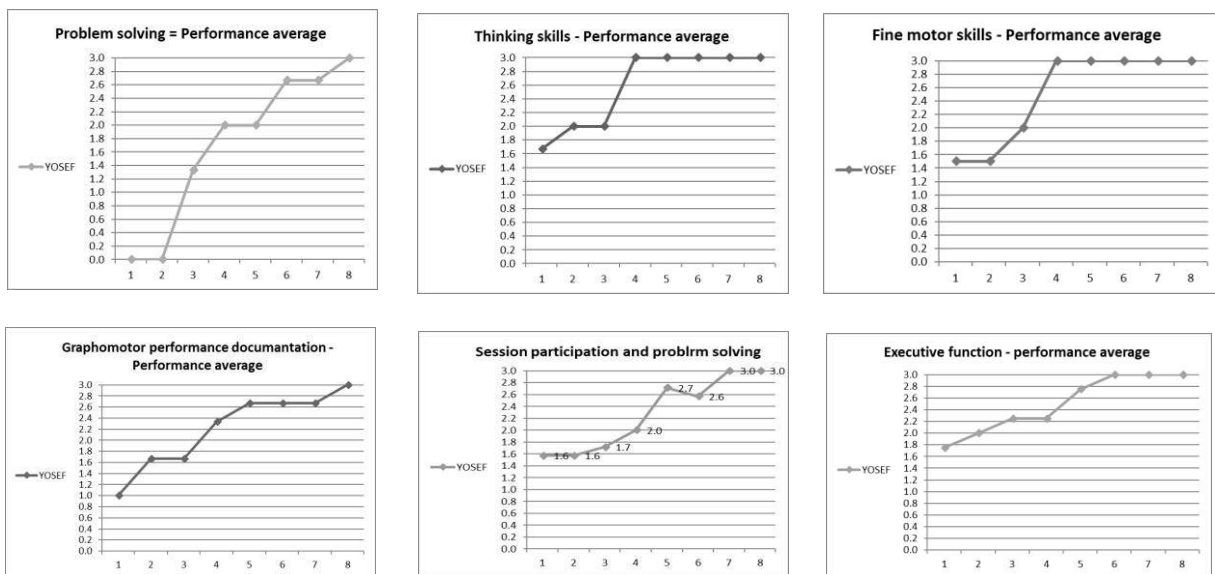


Figure 16: Learning progress along tasks - Yosef

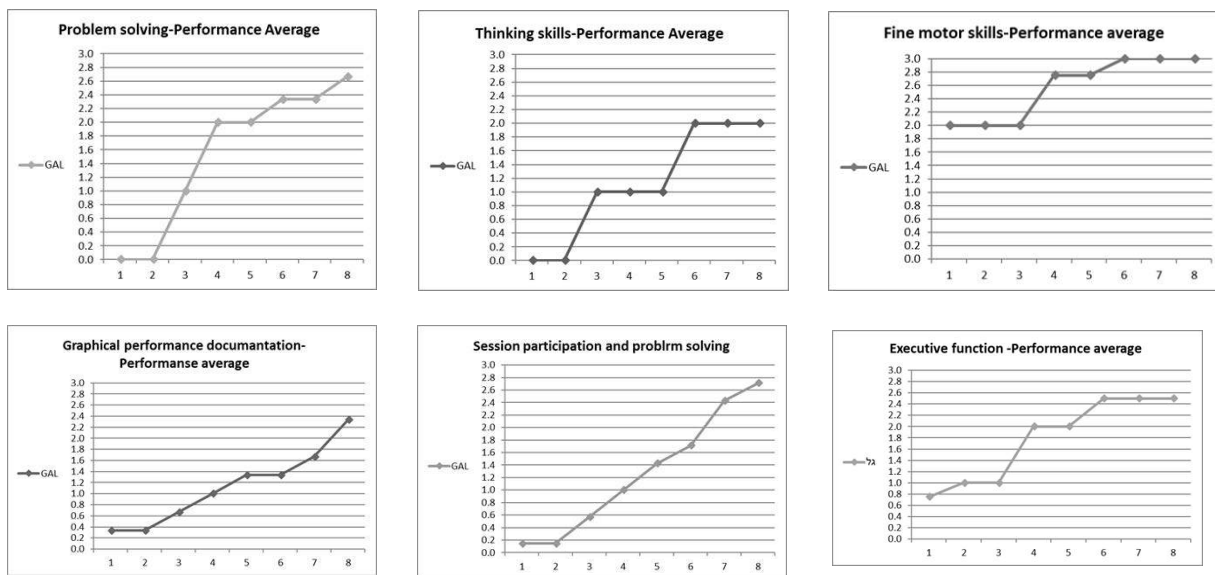


Figure 17: Learning progress along tasks - Gal

For the two children the results showed a significant improvement in all the observed skills. However, while Yosef performed at a higher level from the very beginning of his involvement with the tasks, the case of Gal is notorious. Against the background of his diagnosed problems, the progress in performance and the development of important skills during his involvement in technological thinking tasks was impressive.

#### **4. DISCUSSION**

This study, focusing on special education children, was designed on the basis of a long term research plan carried out in regular experimental kindergartens (Kuperman & Mioduser, 2012).

According to published surveys, more than 50% of students in the special education system have learning disabilities (Leizer, 2000). Children with learning disabilities are unsuccessful in developing their own effective learning style. Unlike other children, children with developmental delays require mediation and support in their learning of strategies essential for life in general and for academic performance in particular.

In the majority of cases, the staff in the special education system try to help the children by closing the academic gaps while teaching knowledge using structured methods (Hattie & Yates, 2014; Rowe, 2006). In this study we chose to expose the children to tasks aiming to encourage learning while trying things out and developing thinking skills, and not just acquiring knowledge. We wanted to examine whether significant progress can be achieved with children in special education performing experiential activities in a technological environment that raises possibilities for: (a) construction - employing fine motor skills; (b) documentation - requiring graphomotor skills; and (c) developing reasoning skills for problem solving. Our intervention program was based on the premise that technological thinking can serve as a tool for reaching many therapeutic goals for children in special education (Bers, Flannery, Kazakoff, & Sullivan, 2014; Bers, 2008).

Following the exposure to the various construction kits, their repeated use in varied tasks, together with imparting significance to the construction, and using it for documentation - we could see that fine motor skills, including hand-eye coordination, strength regulation, in-hand manipulation control and accuracy, greatly improved. The areas of greatest improvement were strength regulation and control and accuracy abilities. The reasoning skills required for attentional control, inhibitory control, planning the construction, and evaluating it during the process, were very poor at the beginning of the study and demonstrated clear progress at its end. It could be seen that the constructions were of very low complexity at the beginning of the process: the children tended to build with two components, it took a very short time, and there was clear difficulty in conferring the construction authentic significance. The complexity of the constructions increased over time, the time spent on it significantly rose, and the children learned to impart their artifacts with significance, and even build an artifact according to an advance plan. The motivation to try out and develop the constructed artifacts increased, and there was increased ability to sustain interest and not give up if they encountered a problem. Regarding problem solving skills, there was progress in identifying and defining the problem, the ability to raise possible solutions, and in implementation strategies and skills. Significant progress has been observed as to the ability to transfer problem solving skills to daily life situations. During the early sessions, we observed many situations in which a child stopped working and immediately moved to a different activity as soon as he had difficulty in performing a task. Later on we saw motivation to struggle, change, and correct, so as to continue building, and even developed the ability to identify that they had encountered a problem and needed to turn to someone for help. There was a significant improvement in executive functions that affect, among other things, everyday learning and problem solving.

The study has several implications on both the theoretical and practical-educational levels. On the theoretical level, we increased our understanding that children with difficulties in the areas of performance and reasoning can improve their performance, reasoning skills, and executive functions, after performing suitable technological thinking tasks.

On a practical level, the results can serve as a basis for creating suitable programs for special education aiming to advance significant skills for successful learning. The results serve as a sound base for understanding that it is important to focus in general and in special education in particular, on advancing learning skills and not just teaching information. It is important to expand the studies in this field and gather additional data.

Following the results of this study, a more extended study was carried out recently including five kindergartens, part experimental and part control groups. Our working hypothesis, also in the new set of studies, is that in contrast with the structured and decontextualized sets of curricular tasks in use in special education - technological thinking tasks, by their authentic, hands-on, creative and motivating nature, and the set of strategies and skills addressed, are of great potential for supporting children's learning and the development of skills and thinking processes crucial for further learning and schooling in regular educational frameworks.

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# Mitcham's Fourth: a case for foregrounding volition when framing Design and Technology Education

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In his 1994 text "Thinking Through Technology: the path between engineering and philosophy", Carl Mitcham presented a typology of four 'modes of manifestation of technology': as object; as knowledge; as activity; and, as volition. In line with Mitcham's own position at the time (and more recently), this paper takes as a premise that the first three of these dominate Design and Technology (D&T) curriculum and research in traditional and restrictive ways. The paper first presents a brief overview of the text and the first three modes; second, presents some philosophical context to the concept of volition; third, reflects in greater depth on 'technology as volition'; and, fourth, sketches a case for foregrounding volition in D&T educational thinking and practice. On its journey, the paper explores concepts of (free) will, choice, decision-making, motivation, intention, human expression, individual and social enterprise, technological (non-)neutrality and incontinence (in Mitcham's sense of the word). The paper is a contribution to the general education case for D&T curricula to take dynamic, humanistic and holistic forms rather than restricted technical-instrumental or purely realist forms.

*Key Words: D&T curriculum, Volition, Will, Student and human agency.*

## 1. INTRODUCTION

Technology, or the making and using of artifacts, is a largely unthinking activity. It emerges from unattended-to ideas and motives, while it produces and engages with unreflected-upon objects. We make dinner, sew clothes, build houses, and manufacture industrial products. We use tools, turn on appliances, answer telephones, drive cars, listen to radios, and watch televisions. In our technological society, all this happens mostly by habit... (Mitcham, 1994:1)

These opening lines of Carl Mitcham's text reflect its engaging title: "Thinking Through Technology: the path between engineering and philosophy". The book offers both a comprehensive overview of the field of technology and an articulation of the case for maintaining a humanities engagement with technological theory and practice. As the book approaches its quarter-century the philosophical, sociocultural and political understandings of technology and its practices have developed hugely. However, just as it is a challenge for Design and Technology (D&T) education to 'keep up' with technological developments (if it really needs to) so it is the case for educators to deepen their understandings of how the phenomenon of technology is at once shaped and world-shaping.

Simplistic understandings of 'technology' hold back qualitatively rich curriculum formulations of D&T education – whether at the policy or classroom level. Those who would constrain the field to uncritical, values-free making and skilling, or to techno-positivist design-poor alliances of the STEM (science, technology, engineering and mathematics) kind not only fail to advance what constitutes 'education' for students themselves but also fail their publics. Mitcham's text takes up the challenge of properly situating technology in existential, socio-cultural, political and moral philosophies.

Mitcham contends (p.12) that the philosophy of technology should: a) be aware of its own history (Part One of the book); and, b) be able 'to articulate a set of systematically integrated issues' (Part Two). He works a rich discussion between *engineering philosophy of technology* and *humanities philosophy of technology* and points out that the term 'technology' is used in both narrow and broad senses by engineers and humanities scholars alike. He defends the broader connotations but distinguishes *four modes of the manifestation of technology* in



the broad sense. Because, '(t)echnology is pivotally engaged with the human' he suggests it should be considered '...in relation to the essential aspects of a philosophical anthropology – with differences drawn between its manifestations in the mind, through bodily activities, and as independent objects...' (p.159). From these he posits technology *as knowledge*, technology *as activity*, and technology *as object*. However, he acknowledges that such a conceptual framework constitutes an oversimplification: that the construct of 'mind' should not be restricted to cognition. 'The will is an equally real if subtle aspect of the human.' Thus, he adds technology *as volition* as his fourth mode of the manifestation of technology.

The concern of this paper is that much Technology Education research and practice currently defaults to the first three modes at the expense of "Mitcham's Fourth". The paper proceeds with a brief sketch of each of the three 'modes' as presented by Mitcham (he devotes a chapter to each). Technology-as-volition is then given greater scrutiny and key aspects along with some additional philosophical background are assembled for reflection on the educational scene. Finally, a case for foregrounding technology as volition in Design and Technology education is sketched out.

## 2. TECHNOLOGY AS OBJECT

Whilst it may be fairly obvious to see types of technology as material objects, Mitcham reminds us that technological objects can also originate from other species and he notes how classifying objects by materiality '...excludes sociotechnical systems from being technological objects in a primary sense...' (p.161). Drawing on Mumford (1934) he offers a 'spectrum of artifacts': clothes; utensils; structures; apparatus; utilities; tools; machines; and, automata (p.162). He expands with other possibilities: tools for doing or performing (letters, numbers, musical instruments); objects of art or religion; and, toys. His investigations embrace animal artifacts; the human experience-shaping nature of artifacts; the social dimension of artifacts; and, the phenomenology of artifacts.

## 3. TECHNOLOGY AS KNOWLEDGE

At a base level, Mitcham contrasts technological knowledge with 'knowledge of nature' – the one of artifacts, the other of natural objects. He then posits that technological knowledge might be considered on a disciplinary basis e.g. architecture and the multiple forms of engineering: mechanical; civil; electrical; chemical; etc. However, no such approaches reveal anything '...about the unique epistemological structure of technology as knowledge.' (p.192). Towards this, he offers a range of distinctions from the least to the most conceptual: i) *sensorimotor skills*; ii) *technical maxims, rules of thumb or recipes*; iii) *descriptive laws*; and, iv) *technological theories* (p193-194).

Different epistemologies of technology and epistemologies of different technologies debate the interaction and relative weights of these various types of technology as knowledge. These are further subject to realist, instrumentalist, pragmatic and other interpretations, although engineers, like scientists, readily assume the realist stance. (p.194)

## 4. TECHNOLOGY AS ACTIVITY

Noting that the modes of technology as object and as knowledge are '...the two most philosophically analysed forms' Mitcham states: 'Technology as activity is that pivotal event in which knowledge and volition unite to bring artifacts into existence or to use them; it is likewise the occasion for artifacts themselves to influence the mind and will.' (p.209). He shows how technological activities manifest themselves across many human behaviours and that they can occur in individual, personal forms or those of the group or institution. As examples of behavioural engagements of technology as activity he offers: crafting; inventing; designing; manufacturing; working; operating; and, maintaining. On deeper examination, the history, politics, economics and socio-cultural relations of each of these begin to open up technology's rich, problematic and contested nature.

## 5. VOLITION AND RELATED CONCEPTS

To step away from Mitcham for a moment, it's worth exploring (in an admittedly lightweight way) the philosophical context of *volition*, that is, *the power of willing* or *the exercise of the will*. The idea of 'free will' has remained one of the great challenges to philosophy for millennia. It is arguably, like technological capability, a key trait of what constitutes being human or...human 'being' (concepts under ever-increasing scrutiny as technologically-driven posthuman and transhuman scenarios present themselves [see e.g. Bostrom, 2009]). Simply put, *freedom* (in Western cultures) can be considered in two broad ways – freedom *from* and freedom *to*. The first refers to the kinds of circumstances that facilitate freedom – such as political liberty and protection of our rights to act as *free agents*. The second refers to using that agency (or not) – having and applying conscious choice and control over one's actions. *Will* refers, at a basic level, to the psychological capacity of most humans for decision-making. Thus, being free to act is one matter but the application of our will to that freedom is what constitutes our decision-making, which includes our *freedom to act otherwise*.

Intimately related to any consideration of our decision-making and acting come *ethical questions*: How should I act? How should we live? What is the right, or best, thing to do? And, in turn, issues of *responsibility* arise. Thus we talk of acting ethically or acting responsibly when we make our technology-related choices in this world. Moral consideration of others also matters; whether 'others' are people, species, environments or, increasingly, technologies (e.g. Verbeek, 2005, 2006). Bound up with this is the rich concept of *intention*.

Standing against concepts like volition is (*causal*) *determinism*: at a general level, the view that all events without exception are the effects of prior events. However, when we turn to the personal level the argument is that: '...all our choices, decisions, intentions, other mental events, and our actions are no more than effects of other equally necessitated events.' (Weatherford, 1995:194). Warnock (1998) points out that the determinist argument is anathema to ethical theory. As she argues, ethics implies choice and that is illusory for determinists. In philosophical terms the seeming mutual exclusivity between freedom and causal determinism is framed as *incompatibilism*.

## 6. TECHNOLOGY AS VOLITION (Returning to Mitcham...)

'Engineering includes distinctive perspectives on and analyses of technology as object, as knowledge, and as activity. It has, however, nothing to say about technology as volition.' (p.247). Thus Mitcham opens his chapter on his fourth mode noting that its exploration calls for a philosophical rather than an engineering approach – one which acknowledges what he calls the protean (variable or versatile) character of volition. Drawing on extensive literature he documents how technologies have been associated with '...diverse types of will, drive, motive, aspiration, intention, and choice' giving these examples:

- the will to survive or satisfy some basic need;
- the will to control or power;
- the will to freedom;
- the pursuit of or will to efficiency; and,
- the will to realise the *Gestalt* of the worker or almost any self-concept (p.247-248).

He cites many will-oriented authors: Spengler on 'technics as the tactics of living'; Ferré's seeing 'technology as practical implementations of intelligence...(where)...practical intelligence is "mental self-discipline in the service of the urge of life...(as a tradition of)...the will to live and to thrive" '; Mumford and others on the will to control and power as potentially antithetical to Ferré's stance; Skolimowski's view of 'technology as a form of human knowledge concerned with *what is to be*' (as opposed to scientific knowledge's concerns with *what is*); Junger, Ortega and Sartre on self-realisation and our existences from whom Mitcham concludes 'Whatever is willed calls forth its appropriate technology'; White's finding 'technology grounded in Christian charity and temperance or what might otherwise be described as an altruistic, disciplined will'; Grant on the dangers of distancing ourselves from our technologies (technology as objects i.e not me/not us) 'Technique comes forth from and is sustained in our vision of ourselves, as creative freedom, making ourselves, and conquering the chances of an indifferent world.' (all pp.248-250).

Opening up a critique of volition in relation to technology Mitcham argues that, of the four modes of manifestation, volition is the most individualised and subjective. He points to the ‘problem of correspondence’ between subjective and objective intentions, that is, while we might know our own acts of willing, we can only infer *from their actions* (including speech) the intentions of others. Here, he discusses *will and ideas* and *will and knowledge* relationships. He also criticises the ‘vacuous’ nature of much discussion around ‘technology and values’ precisely because ‘...it assumes that technology as object, as knowledge, and as activity is value- or intention-neutral’ (p252).

Following Pfänder, Mitcham points to ‘the problem of self-understanding and levels of the will’ which, at a weak level amounts to ‘striving’ as a kind of biological urge or instinct e.g. a hope, wish or desire. Such striving becomes willing when it is strongly ego-centred and we understand our goals can be realised by our own actions. Here, consciousness of self is key. In turn, Mitcham offers Ricoeur’s three levels of what “I will” can mean, namely: “I desire”; “I move my body”; or, “I consent” which he transposes to technology-as-volition as: technological desire; technical motivation or movement; or, consent to technology (pp.253-255).

Mitcham also presents an Arendt extract that reminds us of the temporality of design and technological practices:

(T)he will, if it exists at all...is as obviously our mental organ for the future as memory is our mental organ for the past. (But) the moment we turn our mind to the future we are no longer concerned with ‘objects’ but with *projects*...And just as the past always presents itself to the mind in the guise of certainty, the future’s main characteristic is uncertainty. (Arendt cited in Mitcham 1994:254)

While any discussion of volition invites discussion of ethics, Mitcham shows that traditional ethical assessments of how best to live *only begin* to engage with technology as volition. He identifies what he believes to be two principal shortcomings of traditional approaches. First, they don’t give adequate account of ‘... those technological volitions described by phrases such as “will to control” or “will to power” or even “the pursuit of efficiency”’. Second, in general, they fail to begin to ‘...address the correspondence between different understandings of the good and of technology’ (p.259).

Mitcham devotes his final section of the technology-as-volition chapter to the matter of the *weakness of the will* problem (in traditional philosophy, *akrasia*). However, he specifically chooses the term *incontinence* (the absence of *contentia* or self-control) to ‘indicate a hiatus between knowledge and action’ (p.259). Why is that despite *knowing* what is the right course of action to take that we are capable of doing the opposite? Or, why, despite all our better judgment do we choose to act in ways that are illogical, unreasonable or ethically indefensible? (Here, ‘we’ may be individual or collective.) He says: ‘If power or the ability to act increases, then so must intelligent control – otherwise power will eventually lead to disaster.’ He sets out three preconditions for the full exercise of such intelligent control:

1. knowing what we *should do* with technology, the end goal toward which technological activity ought to be directed;
2. knowing the consequences of technological action before the actual performance of such actions; and,
3. acting on the basis of, or in accord with, both types of knowledge: ‘in other words, translating intelligence into active volition’ (p.260).

Mumford points out that most discussions concerning the responsible use of technology focus on (1) and/or (2) and that (3) is subsumed under questions of societal organisation (cultural lag) or seen as a psychological pathology (e.g. alienation). When (3) is not met then the issue of incontinence presents itself. He notes that the overcoming of incontinence is a matter of:

...education and moral training (and perhaps the restructuring of society). The “artifice” of the polis is a better teacher of ethics than is nature. Incontinence loses its force as a conundrum and becomes merely an indicator of the need to transcend nature with culture. (p.262).

In concluding his chapter, Mumford highlights ‘...an incontinence-related volitional contradiction at the heart of the modern technological project’. He argues that the modern period has seen the valorisation a) of the will over the intellect as the highest aspect of humanity and b) of freedom over justice as the primary aim of politics. Thus, as the technological project is arguably grounded in maximising freedom it, at the same time, presumes the impossibility of incontinence – an at-once-both binary (Keirl, 2015) of freedom set against power/control. Thus the individual (or collective) wishing to exercise free will against/within rationalised technological circumstances, consciously chooses to act against that very rationale.

## 7. BRINGING TECHNOLOGY AS VOLITION TO DESIGN AND TECHNOLOGY CURRICULUM

It would seem that the case for foregrounding volition in D&T education can be articulated as three groups of considerations. The first is philosophical. Design and Technology education, if it is about anything, is about action on the world and any theory of action, as with philosophy of technology, must engage questions around not only volition itself but also around its philosophical relatives. Clearly, matters of values clarification and ethical debate (respectively, *axiology* and *moral philosophy*) are key to discussions of any sense of technology-as-volition. Equally, our will-technology relations introduce *ontological* considerations of our being-in-the-world - the *existential* and the *phenomenological* are engaged. Such philosophical work challenges *determinism* and any ideas of *neutrality* of technologies (in whatever mode). All such explorations illustrate the complexity and holism of the phenomenon of technology and, as a result, the orthodoxies of instrumental rationalism and any claims to technology having a simple positivist-realist knowledge base are turned on their heads. The *epistemology* of D&T education is necessarily dynamic rather than static.

The second set of considerations is curricular and political. If a curriculum is to truly educate about technologies then valorising a particular form of knowledge, or objects/things, or activity (e.g. skilling) as D&T’s *raison d’être* is simply not enough. If students’ understandings about their own (and others’) technological being, efficacy, agency, choice-making, critiquing are to develop then technical ‘problem’-solving and making things will be inadequate. A curriculum for sustainability, for democratic technological engagement, for considerations of consequences, or for social enterprise will engage the vocabulary of volition that Mitcham espouses. This means the centring (rather than the marginalisation) of *design* where competing values, futures-orientation, agency, and choice education are celebrated. Thus, a curriculum organisation is needed that can articulate a holistic, ethical and critical technological literacy and, since rich D&T is necessarily interdisciplinary in nature, it is the obvious leader of such a technological literacy across the curriculum.

Third, come classroom considerations where critical, transformative pedagogies of critiquing and designing are the norm. Here, students learn about their own efficacy; about design as weighing-up of competing variables; about choosing *not* to design in particular ways; about affording respect to other people, other species and to the planet; about choice-making and consequences; about being critical ‘consumers’; and about design as a change-making, futures-oriented practice. To re-phrase the opening quotation of this paper, Design and Technology education manifests as a *largely thinking activity of attended-to ideas and motives*.

Mitcham made his case in 1994 and it continues to speak to D&T education today. He continues to champion the cause with no less vigour twenty years on when he argues for engineering education to engage closely with the humanities saying: ‘How about engineers who can think holistically and critically about their own role in making our world and assist their nonengineering fellow citizens as well in thinking that goes beyond the superficial promotions of the new?’ Noting that we are moving from the human to the *techno-human condition* with dissolved boundaries between the natural and the artificial, between the human and the technological, he calls for engineers to engage ‘...the ultimate Grand Challenge of self-knowledge, that is, of thinking reflectively and critically about the kind of world we wish to design, construct, and inhabit in and through our technologies...The engineering curriculum should be more than an intensified vocational program that assumes students either are, or should become, one-dimensional in their lives.’ (Mitcham 2014:19-21).

As things currently stand, rich concepts such as Mitcham’s technology-as volition remain at the margins (if at all) in D&T curricula. A curriculum that privileges particular objects, making and knowledge leaves no air for the many concepts that can contribute to a truly thinking D&T educational experience for all students. All such

concepts warrant foregrounding because they speak to and interplay with each other to constitute a dynamic, holistic curriculum. If we consider education itself to be a technology then perhaps education-as-volition should become a centrepiece of our deliberations.

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# Using linkography to explore novice designers' design choices during a STEM task

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One of the characteristics of the 21st century is the increase in the information sources available to designers to make their design decisions. However, there is much debate about designers' choice of information that enables them to design effectively. Several studies have reported on the cognitive role played by information sources such as STEM knowledge, sketches, images, three-dimensional models, and the physical environment during the design process. However, current theoretical frameworks do not explain how internal and external information sources contribute to novice designers' moment-to-moment information processing. The purpose of this paper is to examine the use of linkography to investigate how novice designers used information sources during the early phases of the design process. In this paper, we report on a case study in which a group of Grade 8 participants completed a design task requiring them to design a heat retaining food container for street food vendors at a taxi depot. We used a mixed methods case study research design, in which Think-Aloud Protocols were used to access the cognitive processes of the participants. An extended cognition framework formed the theoretical foundations of this study. The preliminary findings indicate that the participants extensively used external information to structure and solve their design problems, with minimal use of STEM knowledge.

*Key words: Design cognition, Information sources, Linkography, STEM knowledge, Technology Education*

## 1. INTRODUCTION

This paper reports on research that is currently in progress for the completion of a PhD. While the final results are not yet available, it is worthwhile to make known the nuggets of information that have been gained in the interim.

Cognitive psychology teaches us that to understand learners' design cognition, researchers should study small increments of thought (Chinn & Sherin, 2014; Goldschmidt, 2014). This implies that the former linear, phase or spiral models of the design process becomes less appropriate for understanding the nature of designers' thinking processes in detail. The underlying assumption of these models is that the design process comprises separate phases and that designers progress from one phase to another, with iterative cycles where necessary. We now know that these models teach us little about the design reasoning processes involved in design. Although these models highlight the procedural nature of designing, they do not reveal the ontological nature of design thinking (Haupt, 2018a; Sung & Kelley, 2018). This suggests that researchers need to consider looking at smaller segments of the design process to understand how learners think and reason during designing (diSessa, Sherin, & Levin, 2016; Goldschmidt, 2014; Hall & Stevens, 2016). One way of studying learners' design processes closely is by using verbal protocols.

Verbal protocols have been used for the last 40 years to study the moment-to-moment thought processes of both individuals and teams of designers. Verbal protocols allow researchers to collect systematic evidence of

designers' incremental thought processes and behaviours as they occur during a design task (Grubbs, Strimel, & Kim, 2018; Sung & Kelley, 2018). The captured verbal reports and behaviours are transcribed and coded systematically, thereafter, analysis occurs by studying the design process in small units. Although the verbal reports can never be a complete representation of designers' thought processes, they do provide some access to designers' reasoning and thinking, which would otherwise not be accessible (Goldschmidt, 2014). Allowing designers to work in design teams also enhances the validity of their verbalisations as teams naturally communicate with each other during their design task (Goldschmidt, 2014). A further strategy to enhance verbal protocols is to include the analysis of visual external representations, including sketches, 3D models and gestures.

Recently, Grubbs et al. (2018) analysed the coding frameworks used to study the verbal protocols of technology education learners engaged in design tasks. Of the seven reviewed frameworks, three frameworks emphasise the procedural nature of designing, while the other four frameworks have a cognitive science foundation and reflect an ontological approach to understanding learners' cognition. However, none of the frameworks capture the dynamics between learners' interactions with internal and external information sources. Instead, it seems that the frameworks espouse predominantly internalist cognitive science theories. To this end, this paper follows an extended cognition framework toward examining learners' cognitive processes by means of linkography.

## **2. THEORETICAL FRAMEWORK**

For the study of learners' moment-to-moment designing, we adopted an extended design cognition lens (Blom, Haupt & Fraser, 2018; Haupt, 2018b). In contrast to classical information processing theories, extended cognition recognises that designers' design task environment encompasses internal and external sources of information, irrespective of domain or level of expertise. Extended cognition developed as a subset of Situated Cognition (Robbins & Aydede, 2009) and Distributed Cognition Theories (Hutchins, 2014) and pays equal attention to computational theories of mind and ecological psychology when studying cognition. The Extended Mind Thesis (Clark, 2006, 2008; Clark & Chalmers, 1998), which rejects exclusive internalist and externalist theories of cognition in favour of an integrated model of cognition (Hurley, 2010; Menary & Gillet, 2017), formed the backbone of our current understanding of learners' cognition during designing.

The benefit of using an extended cognition framework lies in the descriptive power it provides in describing the development of learners' design activity. This is in conjunction with the information sources that they use during designing. In the professional design literature, Cash and Gonçalves (2017) emphasise that there are limited theoretical frameworks describing the development of design procedures in conjunction with information sources. As such, an extended cognition framework provides a means to study how Grade 8 technology learners use information sources during the early phases of the design process.

## **3. METHODOLOGY**

In order to examine how Grade 8 technology learners used information sources during designing, a Think Aloud Protocol Study (TAPS) embedded in a mixed methods case study was used to collect concurrent qualitative and quantitative data (Creswell, 2014). The qualitative data included visual and verbal data, while the quantitative data included temporal data. Conducting a TAPS allowed us to microscopically study what information sources the participants used in the design process, and when they were used. The study was conducted in a low to middle socio-economic region in South Africa. Three participants were purposefully chosen by their teacher to participate in the case study based on their ability to communicate effectively, work together as a group, and proficiently solve design problems using STEM knowledge. The researchers were able to elicit the design cognition behaviour of each group of participants by providing them with a design task, which was adapted from a prescribed textbook approved by the South African Department of Basic Education (DBE). The design task was based on the participants' previous term's work, focusing on concepts of structures and processing. The group of participants was required to design a recyclable heat retaining food container to be used by street food vendors at a taxi depot. During a single two-hour session, we presented the participants with the design task. We then video recorded them as they engaged with the design task. The video recording was conducted as unobtrusively as possible, and the participants were provided with minimal guidance from

their teacher and the researchers. Stationary, tools and materials were provided to facilitate the design process. This paper reports on the first hour up to the point where the participants generated ideas and chose an appropriate design concept.

### 3.1 Analysis of the data using linkography

Linkography was originally introduced to analyse verbal protocols in order to assess designers' design productivity (Goldschmidt, 2014). This method has been extended by several researchers (Cai, Do & Zimring, 2010; Gero & Kan, 2017; van der Lugt, 2005) and is now an established method for studying design cognition with quantitative and qualitative applications. In order to generate the linkograph, verbal utterances are segmented into a chronology of 'design moves'. A design move is defined as "a step, an act, an operation which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1995, p. 195). In this study, verbal utterances were parsed based on the participants' turn-taking, which is a common segmenting principal in team designing (Goldschmidt, 2014). After the verbal utterances have been segmented into a sequence of design moves, a linkograph can be constructed by identifying the links between these design moves (Goldschmidt, 2016).

In order to establish the links between moves, the researcher matches each move with its preceding moves to determine whether a link between them exists (Goldschmidt, 2016). If a link is established, it is called a backlink as it is directed back in time (Goldschmidt, 2016). After all the backlinks have been formed for a design session, one can retroductively speak about a forward link between an earlier move and a move made later in time. Goldschmidt (2014) claims that forelinks are manifestations of future-directed, divergent thinking, while backlinks are manifestations of past-directed and convergent thinking patterns.

Moves that have been identified as having a significant number of backlinks and forelinks are labelled as critical moves (Goldschmidt, 2016). In linkography, critical moves are significant because they are indicators of a high level of interconnectivity between moves, which is typically how synthesis in design is established (Goldschmidt, 2016). Figure 1 illustrates an example of a hypothetical linkograph that the researchers created with the Linkographer software.

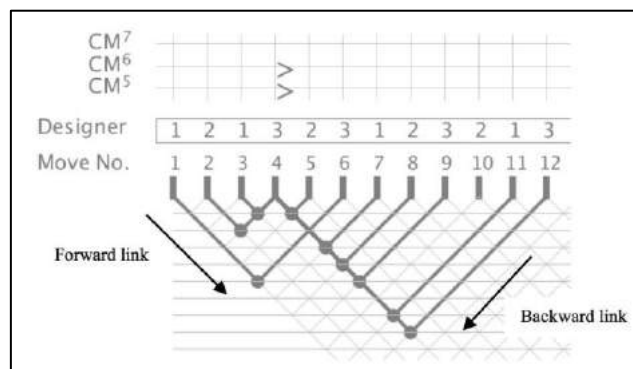
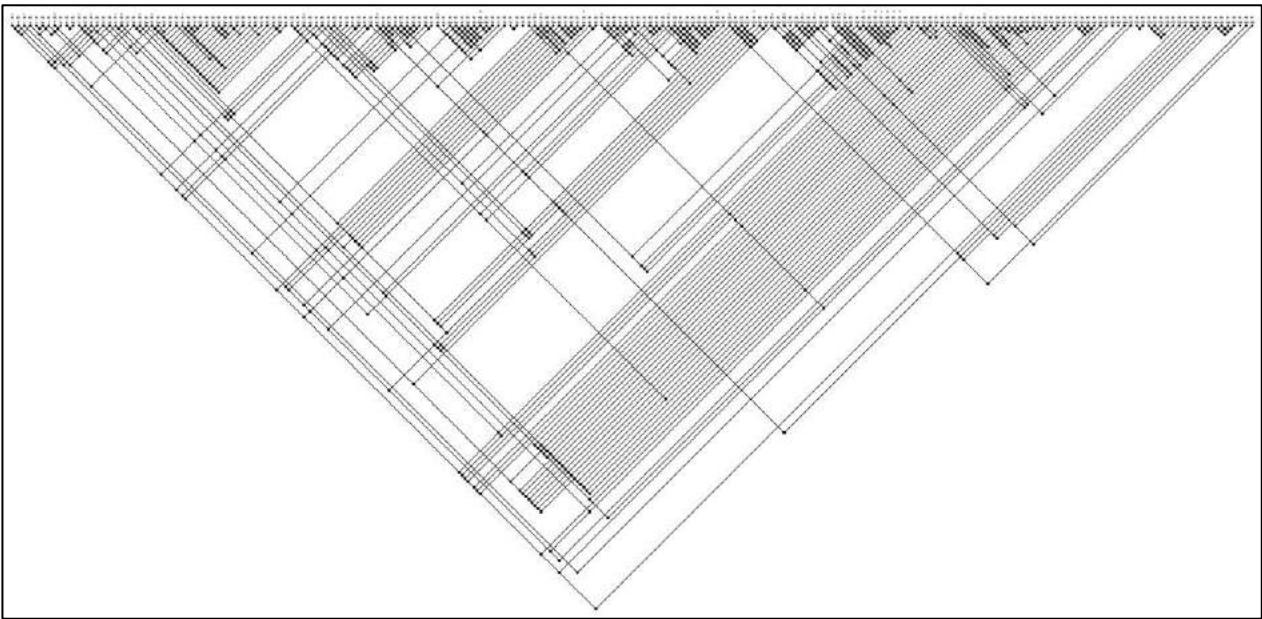


Figure 1: Hypothetical linkograph to demonstrate backlinks, forelinks and critical moves

In Figure 1, the links between design moves are illustrated. In a linkograph, we can distinguish between four different types of design moves: orphan moves (move 10), uni-directional moves (Moves 2, 3, 5, 6 – 9, 11-12), bidirectional moves (move 4) and critical moves (move 4). Orphan moves are unrelated to any previous or future design moves. Unidirectional backlink moves imply that at the moment of their instantiation, the participants were concentrating on what had transpired up to that point (Goldschmidt, 2014). Unidirectional forelink moves imply that the participants are instantiating new thoughts that leave behind what has been done thus far, but to which later moves might form links (Goldschmidt, 2014). Design move 4 is a bidirectional design move because it backlinks to move 3 and 2, but also forelinks to move 5, 7, 8, 9, 11 and 12. If a move contains both backlinks and forelinks, the move can be labelled as a bi-directional move. Bi-directional moves suggest that the participants are planning ahead while still making sure that there is continuity between past design moves (Goldschmidt, 2014). Bidirectional moves illustrate that the participants are exhibiting a rapid shift between two modes of reasoning, namely, divergent and convergent thinking (Goldschmidt, 2016). Critical moves are design moves that are rich in links to other moves and can be unidirectional or bidirectional.



## 4. RESULTS



*Figure 2: A Linkograph of the participants' design session*

The preliminary results of this study can best be presented in visual form. The linkograph, shown in Figure 2 not only allowed us to see at a glance at which points the participants continuously referred back to their previous thoughts or discussions during designing, but also where new thoughts were instantiated throughout the design process. A preliminary quantitative analysis of the types of design moves revealed that 59% of the total 206 design moves were bidirectional design moves. This supports Goldschmidt's (2014) findings, which show that the proportion of bidirectional moves, close to two-thirds, is typical of novice designers. This begs the question: is it an instinctive reaction within the design process, uninfluenced by the level of expertise, that allows the designer to move with fluidity between the past and the future? Further research is necessary to establish whether this trait is commonly to be found in the design process of novice designers, or if this has been inculcated across years of unintentional design thinking during their school programme.

A further finding revealed that there were 20 critical forward linked design moves that emerged during designing, in contrast to only two critical backward linked design moves. This suggests that the participants engaged in more divergent thinking, with minimal convergence taking place. According to Goldschmidt's (2016) findings on professional design protocols, typical ratios of critical forward moves to critical backward moves should be 60:40. Although the participants were engaged in the early phases of the design process, which is known for idea generation phases, it appears that this group of participants paid less attention to taking stock of their previous design moves. Although there were a total of 184 moves with backlinks (unidirectional and bidirectional included) in the linkograph, only two were critical design moves. This suggests that the participants generated ideas but did not necessarily develop, evaluate, or summarise them.

A final preliminary finding related to the participants' information use revealed that the participants leaned more heavily on external information sources (74% of design moves) than on internal information sources (26% of design moves). External information sources comprised a design problem statement, pictorial information (photographs and diagrams), physical objects, and the tangible external representations that they made. Internal information comprised their STEM knowledge, previous experiences, and their design intentions. Although the participants used their prior experiences with food containers extensively (17% of design moves), they made limited interactions with STEM knowledge to make design choices (9% of design moves). In Figure 3, the participants' information use is visually represented with an archiograph on top of the linkograph.

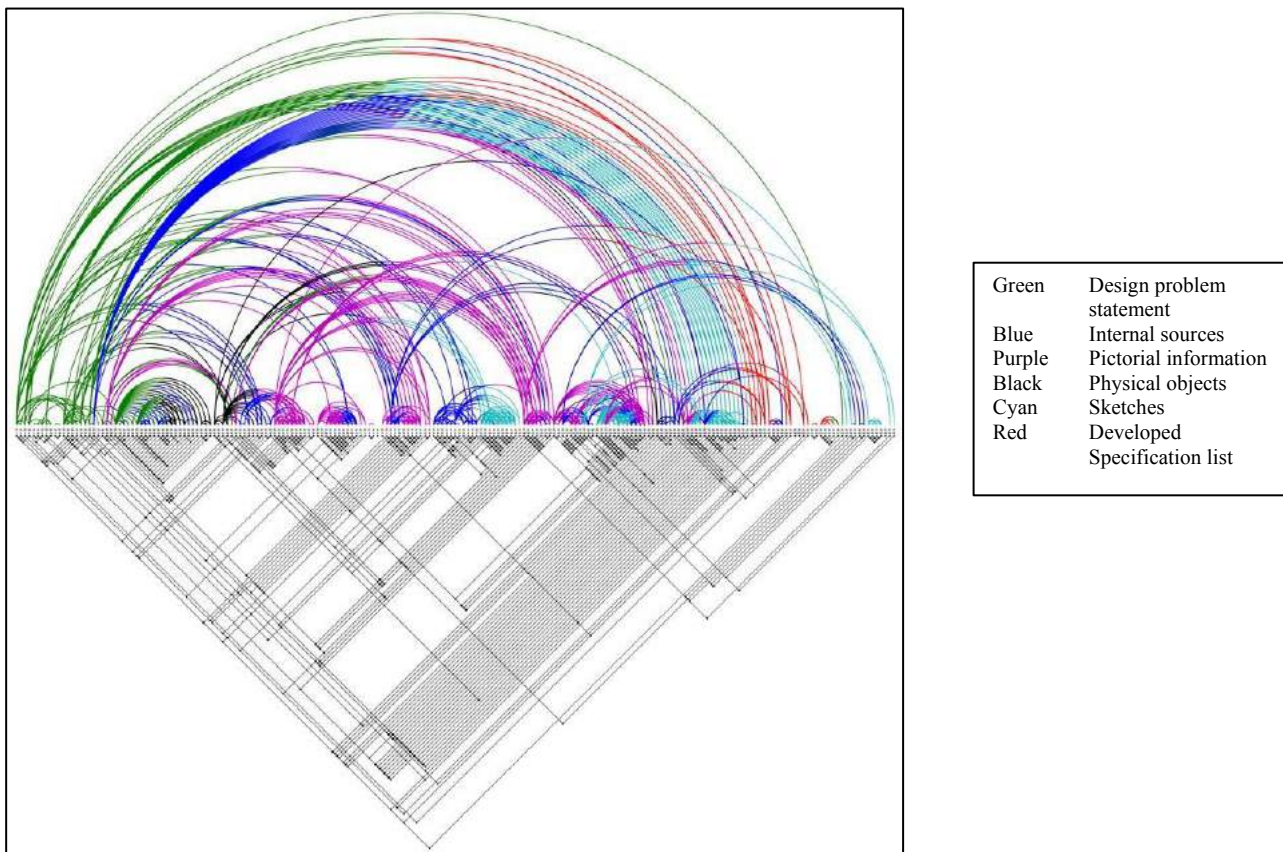


Figure 3: The participants' information use during the design process, illustrated with a Linkograph and an Archiograph

At first glance, Figure 3 reveals how different information sources were, perhaps, mechanisms for generating the participants' design moves. Future studies might want to investigate the nature of information sources in the design task environment, and what role they play in learners' reasoning processes.

## 5. DISCUSSION AND CONCLUSION

This paper has shown that what may be seen as a design activity by school children is, in fact, a complex process that involves various backward and forward connection making. It is worth considering that the deliberate enhancement of these processes through pedagogical expertise may deliver more expert results than is generally expected of secondary school learners. This speaks to tertiary training and the design processes of teachers as they create lesson plans structuring design activities and preparing information sources.

In this regard, this study has shown that external information sources are used extensively in the design process. Therefore, it seems necessary that teachers should pay careful attention to the nature and quality of the information sources that they provide for learners, as these sources facilitate learners' thinking about their design problem and solutions. The sources should not be the product of hasty lesson planning, but deserve to be carefully thought through and judiciously selected based on their cognitive affordances in the design process. In conclusion, the linkograph has been found to be a revolutionary tool in the analysis of the design process as it accurately and efficiently represents the structure of learners' reasoning during designing.

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# Conceptualisation Processes and Making

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For a couple of decades, the corporeality of human thought has been a mundane, if not dominating way to conceptualise human cognition. Most notably, the notion of embodied cognition has gained popularity among researchers of the human mind. Despite the recognition of the centrality of bodily experience in human life, it has not had much impact on educational practices. In technology education the applicability of embodied cognition and other related approaches is particularly clear. Acknowledging bodily experiences as the basis for our conceptual systems implies the importance of the ability to manipulate physical objects. Therefore, the cornerstone of technology education is the aspiration to make and manipulate. This aspiration is important to be understood, supported and utilised in the organisation of learning. Recent trends in any level of education have not stressed the empowerment of the learners by resilient training. The discussion about the roles of technology and the human being typically diminishes the human ability by arguing that tasks that can be performed by technology are no longer necessary to be mastered by humans. However, in this position paper we argue that according to the contemporary interpretation of embodied cognition, the gradual degradation of our ability to use our body to manipulate our physical environment has inevitable consequences in our thought. If our concepts are ultimately constituted on corporeal experiences, the fundamental function of educational systems is to provide opportunities to acquire such abilities. Applying the proposed approach would bring technology education into the very core of all education. On the other hand, the development of technology education should stress the understanding of the physical reality of the real world, as well as the role of the human being as a creative manipulator of the environment.

*Key Words: Embodiment, Conceptualisation, Technology Education.*

## 1. INTRODUCTION: BEYOND CARTESIAN DICHOTOMY

The fast change of lifestyles in the industrialised world has challenged many traditional conceptual frameworks of human society. In many walks of life we implicitly recognise the inadequacy of established perspectives to the world, thus acknowledging the need for new kinds of approaches. New approaches are necessary both in understanding what is going on, and to be able to act in an appropriate manner. In other words, we need concepts to analyse the contemporary world and means to have a desired effect on it.

In the current study education, more precisely learning theories and pedagogical practices have been chosen as a perspective to the on-going changes in the world. The changing roles of human being and technology and the changing role of school as a societal institution have direct reflections in how learning as a phenomenon appears to us.

The conceptions about human learning are constituted on the basis of popular view as well as on academic research. These two – the layman's view and an academic one – were probably almost merging when B. F. Skinner (1970) and other scientists introduced behaviourism as an all-embracing theory of learning. Ever since the days of Skinner the research based view of learning and the popular view have diverged from each other. After behaviourism, no theory of learning has truly found its way to the consciousness of the man-in-the street; either theories of conditioning were simply so well received that it is difficult to fight back even after decades, or the newer theories have turned out to be too difficult to be illustrated for general public. For instance, the subjectivity of knowledge, the cornerstone of constructivism (Jonassen, 1991), is hard to find even in the rhetoric of educationalists, not to speak about colloquial language.

The discourses of learning and education typically contain features from both academia and common sense. Everyone has been at school, and thus, has opinions about school and learning issues. Educationalists, who should represent the research based view of learning, tend to participate in public discourse without making a clear difference between the everyday conception of learning and learning as a theoretical concept. Far too often, the confusion between the everyday view and a more analytical view (see e.g. Merriam & Caffarella, 1999; Ertmer & Newby, 1993) takes place where the theories are supposed to be applied: in school life.

It is interesting to reflect on recent trends in education and to consider these in light of recent developments, particularly those in cognitive science. For instance, from the perspective of embodied cognition (Merleau-Ponty, 1962; Radman, 2013; Rowlands, 2010; Varela, Thompson & Rosch, 1991) which has been a mainstream paradigm in the conceptualisation of human beings for quite a while, the acknowledgement of the corporeality of learning appears to exist in clear conflict with school practices in most countries in recent times. When the paradigm of embodied cognition conceptualises corporeal experiences as the main constituents of our conceptual systems, school practices appear to isolate learners further and further away from physical experiences, replacing them with virtual substitutes.

According to the current understanding, learning is a gradual process, whereby knowledge is built upon the basis of already existing concepts. This constructive learning process is highly contingent upon interaction with the environment. Put simply, the conclusion is that the primary challenge of school education is to enable rich interaction with the real world – the world within which an individual is physically, socially and culturally located. Without physical experiences the construction of concepts is not possible. Even extremely theoretical mathematical constructions are fundamentally based on concepts, which have a corporeal origin (Radman, 2013).

## **2. EMBODIMENT, LEARNING AND TECHNOLOGY EDUCATION**

In schools, subjects are often categorised in terms of those that are theoretical and those that are practical. From the proposed perspective, this type of division is inappropriate; there are no theoretical or conceptual entities without origins in bodily experiences.

There are many schools and teachers whose pedagogy is based on deep understanding and experience of learning as primarily an embodied phenomenon. Most notably, the acknowledgement of the primacy of corporeal experience in learning appears in so-called alternative pedagogies, like pedagogies of Waldorf, Montessori and Freinet. However, these pedagogies have not gained popularity among mainstream schools. On the other hand, though stressing the importance of bodily experiences, the underlying philosophies of alternative pedagogies still typically handle human learning, cognition and the body as discrete entities. The unity of human being; the fundamentally bodily nature of the whole humanity should be articulated in a form that would be comprehensible by educators on a large scale. Therefore, there is the need for a conceptual framework within which the centrality of bodily experience in learning becomes evident and comprehended by any professional educator.

The significance of the proposed approach is thus not limited to the community of educational research. Spreading the understanding of learning as action contributes to the development of schools whose pedagogy is not based on the out-dated Cartesian dichotomy to mind and the body, but on the unity of human being. In the long run, in turn, changing schools implies the changing of the whole society.

In the current study, we are looking at the society from the perspective of basic education. As discussed above, the significance and scope of the study is not limited to formal education, though. When investigating and questioning current conceptions and practices, we inevitably discuss the relationship between human being and all the artefacts that surround him or her (Parviainen, Pirhonen & Tuuri, 2013; Pirhonen, Parviainen & Tuuri, 2013; Tuuri, Parviainen & Pirhonen, 2017; Pirhonen, Maksimainen & Sillence, 2012; Pirhonen & Rousi, 2018). Usually these artefacts can be categorised as technology. In other words, the proposed study goes deep in the relationship between human and technology.

In school context, the relationship between humans and technology takes various forms. We are talking about our relationship with technology when discussing e.g. the ventilation of school buildings and the related health issues. Likewise, when choosing the right kind of pen for each exercise (Mangen, 2016), it is a human-technology related task. The acoustics of school buildings as well as their visual appearance are not only aesthetic but also technical topics.

Recently the talk about schools and technology has been strongly biased to the utilisation of digital technology (Pirhonen, 2010). In the current study, we are aiming at adopting a more holistic approach, handling everyday school life as it really is, without prioritising certain form of technology. However, due to the penetration of technology into all walks of life, the relationship between technology and us will be salient.

Technology related issues are present everyday in school life. A popular example of the importance of this topic is the plethora of recent studies concerning reading and writing skills. We are talking about *new literacy* and argue that new forms of writing are emerging. These fashionable approaches suffer, however, from a relatively narrow and technology driven view of reading and writing. For instance, writing with pen and paper vs. typing with a keyboard of a computer, are often treated as interchangeable activities. The application of embodied view of human cognition reveals that these two are qualitatively essentially different and should therefore be separated from each other in credible analysis of writing. In other words, typing and writing are extremely different kind of activities for a human actor (e.g. Mangen, 2016).

In technology education, embodiment is an appropriate approach for a number of reasons:

- (i) Conceptualisation relating to e.g. technical, mathematical and physical objects is a basis for technological problem solving.  
As argued by Lakoff and Johnson (1980), our language, thought and conceptual system are based on metaphors. By metaphor we do not refer to a simple, classical definition of it as a 'figure of speech'. Rather, we take metaphor creation as a focal human strategy to adapt to the environment by creating relevant concepts in each context on the basis of existing ones (see e.g. Pirhonen, 2005). The ultimate concepts, in turn, stem directly from bodily experiences.
- (ii) Manipulation of physical objects is essential in design and problem solving.  
Acknowledging corporeal experiences as the focal element of human thought inevitably leads to the conclusion that design and problem solving are fundamentally based on interaction between human actor and physical objects.
- (iii) Manual skills and the process of their acquisition are focal skills of thought.  
Provided that human conceptualisation processes are based on bodily experiences, it is essential to consider how those experiences can be acquired. A natural conclusion is that human ability to interact with the environment is largely dependent on individual's practical skills.

It appears that the major challenge of educators and researchers of education is to narrow the existing gap between the scholastic view of human learning and the current educational practices. Since the essential difference between the two currently seems to be in the role of human body and physical activity, it can be argued that technology education would be an excellent candidate to pilot and illustrate a new kind of learning paradigm: Technology education quite naturally embraces conceptual structures with physical applications and relating physical activities.

The proposed, technology education driven approach to learning would contribute to the development of theories and practices of education in many ways. We now focus on two things relating to the primacy of the physical and their reflections on technology:

- (i) If the very concept of learning would be defined as an embodied phenomenon, the focus of interest would shift from abstract concepts to real world events. A mundane example is the above-mentioned writing; by stating what really happens in the writing process would reveal the determining role of chosen writing technology. The traditional talk about writing as a process of formulating words and sentences by following grammatical rules only provides a very limited view to writing. In the proposed, embodied view even issues like the form of the pen and pen tip, required force, quality of paper, writing position, lighting, ambient noise and other aspects of the writing environment, can be analysed in

terms of writing experience. The related learning process concerns all of these and requires a lot of time consuming exercise and efforts. The resulting skill is thus firmly bound to the physical body and performance. The relating knowledge can largely be described as tacit. Going through such a process an individual acquires important human capabilities to interact with the environment.

In other words: Even when discussing writing, in embodied view we are unable to pass by technological discussion. In fact, embodied view of human learning inevitably makes technological and other physical issues primary constituents of learning. Consequently, understanding one's own learning process requires understanding of technology even if this were not deliberately stated.

- (ii) If the analysis of such an everyday activity as writing ends up to this important notion of the concept of learning, how about the complex and demanding functions relating more exclusively to technology education? A good example is woodcarving (Gulliksen, 2017) – how the process of manipulating the material with hands and knife turns into an embodiment of humanity. The tools and the material become an extension of cognition (Clark & Chalmers, 1998), and the physical outcome of the process becomes part of the person's identity.

The argument above is a result of considerations among scientists and philosophers of education over decades. The same phenomenon has always been familiar to practitioners of education, like teachers of basic education: When a pupil puts his or her heart into the creation of something, that thing inevitably becomes valuable for the pupil. Sometimes teachers and even teacher educators understate the value of the physical outcome by using clichés like “process is more important than product”. Experienced teachers, though, recognise the intense relationship between the physical outcome of the process and the pupil.

### 3. DISCUSSION & CONCLUDING STATEMENTS

The difference between science and technology has often been discussed. A typical conclusion concerning the characteristics of these phenomena is something like this: Science is how things *are*, while technology is how things *could be* (see e.g. Dugger, 2010). In science, the data has been collected from the past circumstances. Technology, in turn, has focus in the future. This simple characterisation of science and technology may confuse especially those working in the field of educational science. Isn't education, if anything, a science that is future-oriented?

It appears that the decades long tendency in educational science to get scientific status has often led to aspiration to adopt the paradigm of science from natural sciences. Sometimes, this approach has resulted in ethically questionable conclusions. An educationalist with this kind of orientation may collect data from school children in the middle of an evident disaster, return to the researcher's nice and quiet office and make statistical analysis of the data. Finally, the researcher publishes a report in which the researcher describes this as an “interesting” phenomenon. It would be extremely “unscientific” to report that the school was a total disaster and to suggest how things should be organised there.

If science is about how things are and technology how things could be, could technology education show the way to combine the two? Could education be – like technology – about how things could be? Finally, could technology education be the discipline to bring the concept of embodied cognition to all educational practices? If yes, it would do a favour for the whole field of education and beyond.

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# The Delft Research Programme on Design for Concept Learning

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Doing design activities in education has an intrinsic value: pupils learn how to design and they get an understanding of the nature of designing and therefore also an understanding of technology. Doing design activities also has an extrinsic value. Pupils also learn other things by designing. One of these things is: concept understanding. This is the focus of the Delft University of Technology educational research program, that is related to the teacher education program at this institute. The research is used to feed courses in subject pedagogy for science and technology. Some studies have already been completed and others are still ongoing. Some studies deal with primary education, others with secondary education.

*Key Words: design-based learning, design-based research, concept learning.*

## 1. INTRODUCTION

This paper aims to describe the STEM education research program that is currently executed at Delft University of Technology, the Netherlands. The research programme supports the teacher education program for science, mathematics and technology teachers. This paper does not describe a research study, but only presents a snapshot of the research at Delft. In this paper the theoretical background for the programme will be discussed, as well as the preferred methodology for our research, some first results will be reported and finally some remarks will be made about the possible future of the program.

Design plays a vital role in the curricula for (design and) technology education in most countries today. Pupils are challenged to come up with products and processes that are new, at least for them. This has not always been the case. Originally it was particularly England and Wales that had design activities prominently in the curriculum. No doubt the international contacts that emerged in the 1980s and onwards were one of the causes for the dissemination of a design-based approach for technology education from England and Wales to many other countries (De Vries, 2018). One obvious good reason for having design activities in the curriculum is that design is one of the primary processes in technology and engineering. Being involved in design activities provides an understanding in one of the most important features of technology and engineering. Even when technological literacy is taken as the most important goal of technology, which implies a consumer rather than a developer perspective, it still makes good sense to have design in the curriculum, because critical consumership is not well possible without an understanding of technology and design as constant decision making based on considerations in which all sorts of values play a role. The importance of design as an element in the curriculum becomes even stronger when (design and) technology education is also seen as an orientation on technology and engineering as options for a future study an career. In summary, the intrinsic motivation for having design in the curriculum for (design and) technology education is evident.

There are, however, also extrinsic motivations for having pupils perform design activities in class. One of these is the assumption that design is a process in which knowledge plays a role. This knowledge can be of different natures. For a long time it was thought that technology was merely the application of knowledge for natural sciences. Even though philosophy of technology has falsified that view, the use of scientific knowledge in design is still present in many cases of technological developments. What we have come to see more and more is that technology also has its own knowledge domain, other than science. That knowledge also interacts with the process of design. Furthermore there can be knowledge of other academic disciplines than natural sciences, like psychology, economy, law, ethics, aesthetics, etcetera. It is this rich combination of knowledge involved in design that makes design an attractive pedagogical strategy for learning that knowledge. Design is a process in

which knowledge and understanding that was previously learnt can be deepened and enriched, but also new knowledge can be learnt through design.

This two-way interaction between design and knowledge of various kinds made design attractive as a focus for a research programme particularly in the setting of the Science and Communication (SEC; see <https://www.tudelft.nl/en/faculty-of-applied-sciences/about-faculty/departments/science-education-and-communication/>) Department at the Delft University of Technology (Faculty of Applied Sciences). Although the name does not carry that message well, science as well as technology education belong to the task fields of this group. The task of this group is threefold: teacher education, educational research to support this teacher education, and activities for further professionalization of teachers. The scope of these tasks cover the whole range of STEM disciplines. There are specialisations for physics education, chemistry education, mathematics education, information/computer education, technology education and two integrated STEM subjects in the Dutch curriculum (Nature, Life and Technology, <http://betavak-nlt.nl/nl/p/vereniging-nlt/>, in upper secondary school and Research & Design in so-called Technasium secondary schools, <https://en.wikipedia.org/wiki/Technasium>). Another reason for design being attractive as a research focus for this group is the institutional environment: there is ample experience in design within the Delft University of Technology. In the Faculty of Industrial Design there is even a Department for Design Methodology. Also there is a network of colleagues who are involved in the teaching of design-based courses and projects in the various faculties (like mechanical engineering, electrical engineering, architecture, air and space engineering, maritime engineering and civil engineering). Since 2008, a research program has been developed in the SEC group that focuses on design activities as a pedagogical strategy for concept learning. Both permanent staff and Ph.D. students and postdocs are involved in this research program. First Ph.D. theses have already been defended successfully and members of the team have contributed to science, mathematics and technology education conferences.

## 2. LITERATURE REVIEW

There is not that much research about design-based concept learning and so far the outcomes are ambivalent. Some studies suggest that pupils do learn concepts by design, but they do not provide evidence that design-based learning gives better results than traditional lecture-based learning. Theoretically there are reasons for expecting better learning by using design activities. One reason is that design provides good opportunities for realising cognitive conflicts between pupils' intuitive (but wrong) ideas ('misconceptions') and reality (Akpınar, Erol & Aydoğdua, 2009). For instance, when pupils start designing a boat based on the assumption that big objects (like the big tanker they may have seen recently) will float and small objects (like the nail that they recently dropped in the water) sink, this will probably lead to failing designs. Pupils will be confronted with a clash between their intuitive notions on sinking and floating and the reality of sinking and floating that is scientifically described in Archimedes' law. This experience will make them willing to 'unfreeze' their intuitively developed ideas and start investigating how it really works. Thus the expectation is that they will learn the concepts involved in more engaging way than in a 'dry' experiment or by written work. It remains to be seen, however, if pupils really recognize this alternative way of making the design work, or if they will seek new trial-and-error based ways of searching. If the project is such that this kind of behaviour is rewarded because it does lead to success, then of course the design-based approach does not lead to any improved concept learning. Thus the design-based approach fits in a constructivist ideal in which pupils actively (re-)construct their conceptions. The fact that one concept can be used in different consecutive design projects makes it also suitable for the concept-context approach that is promoted in science education nowadays (Pilot & Bulte, 2006). Design is then a context in the sense of a social practice in which pupils can participate. In the Learning-By-Design project that was led by Janet Kolodner, a substantial effort was made to investigate the effect of design-based learning (Kolodner, 2002). One of the primary findings of that project was that probably the teachers is the key to successful design-based learning. If (s)he does not actively evoke the use of concepts in the design process, pupils will not use them. At the time the Delft research program started, there was not yet evidence that a more active teacher role did indeed result in better concept learning. Part of our research focused on finding that evidence.

If indeed the teacher is so important for design-based concept learning, then it becomes crucial that the teachers have adequate Pedagogical Content Knowledge (PCK) that enables them to conduct design-based concept learning processes. For that reason, PCK became an important topic in the SEC research program. PCK is a

concept that is still in development. It is the personal knowledge a teacher has based on which (s)he develops and realises education (Shulman, 1986). One conceptually confusing aspect in the PCK terminology is the use of the word 'knowledge'. In epistemology this term is differentiated from 'belief'. One may believe all sorts of things, but only a subset of those beliefs can be justifiably called 'knowledge'. The whole history of epistemology is to find the criteria that determine the difference between 'merely a belief' and 'knowledge'. It is only the stern sceptics that will hold the opinion that there is no difference, but most philosophers see the need to make a distinction, whatever it may be. In the PCK discussions this need seems to be absent. Any belief teachers hold about the education of their specific discipline is seen as part of his/her PCK. In principle that is fine, but then the term Pedagogical Content Belief would be more appropriate, at least philosophically. Nevertheless, the PCK literature is quite relevant for research into design-based concept learning, particularly in the light of Kolodner's finding that teachers are an extremely relevant factor in the process.

### 3. METHODOLOGY

In the SEC research program for educational research there is a strong preference for design-based research. This is, of course, not necessarily the consequence of the fact that the research is about design. There are good options for doing research about design in classes other than design-based research, and there are present also within the SEC research program. What makes design-based research attractive is its direct impact on educational practice. Design-based research always has a twofold aim: providing new theoretical insights and delivering improved practice (The Design-Based Research Collective, 2003). Design-based research is a sort of engineering approach to research. Much of education research is purely descriptive, like natural science research is. It is concerned with reality as it is, not reality as we want to make it. There is, no doubt, good use for descriptive research in educational sciences. Without an understanding of how people think and learn, it is difficult to make sophisticated changes. But it can be questioned if a full understanding is necessary before making changes. Sometimes intuitive notions can already be sufficient to make a decent start. In the end, educational sciences ought to be directed towards changing reality, and in that respect the engineering sciences are a better role model for them than the natural sciences (alternatively one can think of the medical sciences as an appropriate role model for the educational sciences).

Design-based research is like engineering. First a prototype is developed, based on available insights. Then the prototype is tested for its functioning. Then the engineers start making systematic variations to investigate the influence of different variables on the functioning of the prototype. Some variables may appear to have little or no influence. That is nice for the designers, because it gives them freedom to give that variable a value that fits with other needs than functioning. Those variables that do matter, can be given what experimentally appears to be their optimal value and thus the prototype is improved stepwise until time and money is up and the prototype is declared the final design. In education, the situation is often more complex, as many variables are related and one cannot always nicely change one variable and leave all the others untouched. That is why design-based research is sometimes seen as methodologically inferior to experimental settings where an artificial situation is created in which there is more control over the variables. It can be questioned, though, if that is really the case, because even in an experimental or quasi-experimental research setup it is difficult to separate and control all variables.

Design-based research can only be done fruitfully in close cooperation with practitioners. That is why it is attractive to do it in the context of a teacher education program that also provides further professionalization activities. Student-teachers spend part of their time in schools getting their first experiences in teaching. That provides a wonderful opportunity for design-based research, as these student-teachers can take 'prototype' activities to their schools, teach them, and then collect data about what happened. These data can both be used by themselves, as a small research assignment is part of their teacher education program. But also the Ph.D. students in the program can use those data, and often they are the ones that have supervised the student-teachers in developing and executing the 'prototype' activities. Alternatively, the permanent staff that teaches the subject-specific pedagogy courses can play that supervising role and embed the design activity in those courses. Thus, different activities and actors get connected and become one coherent totality.

#### 4. PRELIMINARY RESULTS

The most extensive study in the program so far was a Ph.D. thesis on design-based concept learning in physics education, both at the level of teacher education and at the level of secondary education. The study showed that Kolodner's suggestion to give the teacher a more active role indeed resulted in improved concept learning (Van Breukelen, 2017). Most studies in the program are still ongoing. One study is involved with the role of formative assessment in design-based concept learning and the way this can be enhanced in the PCK that teachers have. This study is done in the context of chemistry education. The researcher, a Ph.D. student, worked with Professional Learning Communities (PLCs) consisting a chemistry teachers. Under guidance of the Ph.D. researcher, the teachers developed a project for designing toothpaste and in another PLC they developed a project for designing a cup that can heat the liquid in it by a chemical reaction of the materials in the side of the cup. By observing and interviewing the teachers she found first suggestions that working in a PLC enhances the participants' PCK that is needed for using formative assessment in design-based concept learning (Stammes et al., 2018). Another study, again for chemistry education, focuses on scaffolding as a pedagogical strategy that can support design-based concept learning. For this study there are no data yet.

A study on design-based learning in primary education was conducted regarding the concept of systems (Koski, 2014). It appeared that young children had difficulties in recognizing the systems notion in complex objects. The researcher developed an activity that was tried out by both an experienced primary teacher and a student-teacher and both felt comfortable in working with this activity. There were also indications that the children developed first notions of the system character of the device they developed.

#### 5. DISCUSSION

From the beginning of the SEC educational research programme, there has been a place for studies that were more loosely related to design-based learning or even outside this scope. Several studies are concerned with primary education. Those are embedded in the Science Hub that develops activities for primary teachers on design. There is, however, no teacher education related to those activities, like with the secondary education oriented part of the SEC activities. Therefore the need to have a link with concept learning is less prominent and other interesting issues can be chosen for research. In this case, we have studies into the development of creativity through design, studies into the early phases of design and how to get young children involved in those early phases, and design-based studies that aim at developing a toolbox for primary teachers that enables them to conduct design projects in which children design for external partners (this project is done in cooperation with the Faculty of Industrial Design).

Other studies that are more loosely related to the program core are those into gamification in physics education (that project is related to concept learning, but not to design) and practical experiments in physics education and their contribution to learning how to argue properly about data. Another current study deals with the problem of transfer from mathematics to physics pupils have. A recently finished Ph.D. project dealt with the extent to which curricula in secondary and tertiary (engineering) education presented a realistic image of technology and engineering (Ghaemi Nia, 2017). The presence of design played an important role in that study, but it did not involve classroom activities and thus was not of a design-based nature. Finally there is a still ongoing study into pupils' and teachers' perceptions about integrating design and research activities (particularly in the context of the new Dutch integrated STEM school subjects Nature; Life and Technology, and Research & Design). A remarkable first outcome of this study was that pupils strongly prefer to do design above research (Vossen et al, 2018). Apparently they did not get any chance yet in the curriculum to experience that investigating can be as exciting as designing, assuming that there is not already a 'correct answer' in the book.

It is and always will be a challenge to find a balance between guarding the focus of the research program and preventing that the number of projects that are only indirectly related, or even unrelated, to the program core will increase to such an extent that the focus is hardly recognizable. Yet, for funding we are dependent on opportunities that are offered nationally.

Another challenge is the relation with the other half of SEC, namely the Science Communication component. This component has a separate track in the SEC master program (of which the Science Education track is the teacher education program), and also a research program to support that. The focus for the Science Communication program is not, as one may expect based on intuitive associations, popularization of science and technology, but strategic communication in technological innovation. The combination of education and communication is interesting because there is obviously a communication dimension in education and an

educational dimension in strategic communication in technological developments. We have already explored what possibilities this can provide in terms of common themes and interests (which has led to a publication in the Sense International Technology Education Studies series; De Vries & Van der Sanden, 2016) and now try to elaborate the idea of using communication in innovation as a common theme for both SEC components. Strategic communication is as important in educational innovations as it is in industrial and business innovations, and therefore we see challenges in exploiting this communality between science education and science communication for further research.

As this paper did not describe a research study, there is no conclusion to be drawn in the formal sense, but hopefully the description given above has provided an insight into the way at Delft University of Technology we use educational research to support teacher education. By involving staff, master students, Ph.D. students, teachers in schools in our research and by choosing primarily for design-based research, we experience our research as a positive input for our teacher education program. It almost feels like a bonus that it also results in academic publications, because our first aim is to improve education. Of course we are aware of the fact that for further dissemination the academic publications are valuable, and particularly for the Ph.D. students it is a must to have journal articles as output and basis for their theses. Still, the improvement of educational practice remains our primary motive for doing educational research and in that sense we believe our educational research programme fulfils a useful function.

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# Kindergarten Programming goes Mobile

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The dyad “programming environment” and “programmable device (e.g., robot)” in the educational scene underwent several transformations in configuration over almost fifty years, since the first programmable floor turtles appeared. From the turtle’s migration to the screen, through its revival as physical device in the Lego-Logo system (and subsequent descendants), the loss of the robot’s “umbilical cord” when communication became wireless (adding spatial flexibility and freedom to the robot’s navigation but at the same time challenging children’s understanding of the communication and control process), and currently the transition to the mobile, “almost wearable” programming environment. Each transition brought about new questions about children’s understanding and learning. The interaction with technology allows kindergarten children to explore and be engaged in technological thinking and to construct a solid basis for the development of complex ideas, through direct manipulation of physical objects. The Kinderbot environment scaffolds this learning experience by providing tools to think and experiment with, as well as a structured pedagogical program. Originally designed as a desktop environment, recently a mobile version of Kinderbot has been developed and implemented. The findings from the initial comparison between the desktop and mobile experiences, reported in this paper, outline three key themes. The first concerns the **perspective of the child programmer**: In mobile programming separation and delays characterizing desktop program-first-then-run disappear and spatial perspectives become unified – the programmer is able to enact the robot’s behaviour while programming “in situ”, where the action is. The programming environment becomes “almost wearable” accompanying the programmer and the robot in the physical space while the actual commands are executed. The second focuses on differences among desktop and mobile programming in different **phases and modes** in the programming experience. The third theme relates to differences in aspects of **collaborative programming** processes.

*Key Words: Mobile programming, enacted programming, educational robotics*

## 1. RATIONAL AND BACKGROUND

Over the past 50 years, since the introduction of the programmable floor turtle, the dyad “programming environment” and “programmable device” (e.g., robot) in the educational scene underwent several transformations in configuration (Resnick & Silverman, 2005). These transformations included stages such as: The turtle’s migration to the screen (e.g., first as in Logo, and more recently in Scratch and Scratch Junior); its revival as a physical device in the Lego-Logo and subsequent systems (e.g. Control Lab, generations of Lego programmable bricks, and KIBO); the loss of the robot’s “umbilical cord” when communication became wireless (adding spatial flexibility and freedom to the robot’s navigation but at the same time challenging children’s understanding of the communication and control process); the introduction of tangible programming which allowed to replace the mouse and keyboard with tangible manipulatives (e.g., “smart” blocks, Belk, 2013; wooden puzzle pieces, Rave & Mioduser, 2014); and recently, the transition to mobile programming environments. Each transition brought about new questions about children’s understanding and learning.

Mobile devices have vast potential for supporting learning and learners. They have become a significant part of daily life, integrating seamlessly with a range of common activities to the point of being regarded as MindTools

and as “extensions of the self” (Belk, 2013; Resnick & Silverman, 2005). The qualities of mobile devices in the context of learning and above all, the fact that unlike a desktop computer, they do not constrain the learner to a fixed location, may transform how the child programmer experiences physical behaving devices. Our current research aims to gain understanding of children’s programming experience with a *mobile* learning/programming environment used in kindergartens (the Kinderbot system) compared to their experience using a *desktop-based* version of the system. The preliminary findings reported here, unveil major themes and questions arising from the “migration” from desktop to mobile, and suggest directions for further research.

The main question addressed was: *What characterizes children’s programming (concerning, e.g., skills, strategies, collaborative work) in the transition from a desktop-based to a mobile programming environment?*

## 2. METHOD

### 2.1 The programming environment

“Kinderbot”, the programming environment used by the children in this study, has been designed to support and scaffold the acquisition of basic programming concepts, and to advance the technological thinking of kindergarten children. Rooted in Papert’s constructionist vision, and his conception of the learning value of the combination of the physical programmable “Turtle” with the Logo programming language, the environment combines symbolic and physical components and allows for playful investigations of both abstract and concrete concepts (Papert, 1980; Mioduser, Levy & Talis, 2009). Kinderbot was originally designed as a desktop programming environment; recently, a mobile (tablet) version has been developed.

The system comprises a (virtual) programming environment, a (physical) robot (built using Lego’s EV3 programmable brick), and (physical) landscapes for the robot’s navigation. The visual user interface (Figure 1) allows the programmer to control the robot’s behavior by constructing programs using icons that represent inputs (e.g., incoming from a touch or distance sensor), outputs (e.g. movements based on activating motors), and configurations of inputs and outputs (e.g., a linear sequence of instructions, a conditional statement). The programming sequence is structured in modes of increasing difficulty (shown at the right of the Figure). The basic modes (1-3) focus on acquiring the basic competencies of controlling the robot and sequencing commands (from immediate mode activation up to creating a script for further running). The more advanced modes introduce the definition of routines (mode 4) and rules of increasing complexity linking between measured inputs and outputs (modes 5-7). The structure and use of the environment are similar on both the desktop and mobile versions, aside for the touch operation modality (e.g., tapping, dragging) in the mobile version. In this paper, we focus on the children’s experience using the first three modes - as they form the basis for acquiring the symbolic language for controlling the robot’s behavior (Mioduser & Levy, 2010).

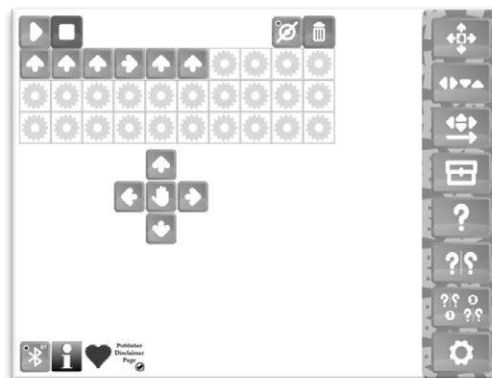


Figure 1: the icon based Kinderbot UI

## 2.2 Data collection

Data collection was conducted by means of: (a) observations of children's performance; and (b) semi-structured interviews with four teachers who use the programming environment in their kindergartens. In the following preliminary data and its analysis are presented.

Naturalistic observations of ten children (age 5-6) in regular kindergarten setting engaged with the mobile and desktop environments were conducted. Each observation session was 20-30 minutes long, the children were observed while constructing routes and creating narrative contexts for the robots to travel through. Concerning ethical issues, the study was conducted in a kindergarten which takes part in a comprehensive project called "Developing Technological Thinking". Parents approved the participation of their children in the studies as well as the use of photography for research and academic purposes.

The teacher interviews focused on issues such as the way children manipulate the mobile device, their posture and position relative to the robot's navigation, their displacement in space, mistakes made, and communication issues. The mobile version of the environment has been initially implemented in two kindergartens. Hence, two teachers had experience with both the desktop and mobile environment while the other two had experience only with the desktop environment. The two teachers who had experience with both environments were also asked to describe their understanding and insights concerning the differences in the programming experience.

## 3. FINDINGS

The following three main themes arose from the analysis of the data and the comparison of the desktop and mobile experience: Changes in the programmer's perspective; changes in foci and learning patterns in programming; changes in patterns of collaboration among peers while programming.

### 3.1 Theme one - changes in programmers' perspectives

In the desktop mode, there is a physical separation between the location of the computer and that of the robot. The programmer must face the computer screen for entering the commands, while the robot is in a distant position. It even may be pointing to a different direction than the indicated by the commands in the computer screen, meaning that, e.g., it's "ahead" and the "ahead" icon (pointing upwards in the screen) differ in spatial configuration. Hence, to control the robot and to provide commands for its movements, the programmer needs to be able to visualize the robot's perspective while sitting in front of the computer screen. A common strategy that children naturally apply, is to move back and forth between the two spatial worlds: the screen programming environment and the physical robot's scene - thus switching cyclically between the physical/concrete environment to the virtual/abstract environment.

In contrast, with the mobile interface, the programmers naturally tend to take position in the vicinity of the robot facing the same direction as the robot, thus taking the perspective of the robot and following its movements while the commands are performed. In other words, the physical distance and gaps in orientation between the programming environment and the programmed object becomes minimal, and the separation (spatial, and in some modes also temporal) between the symbolic creation of the action and the physical execution of the action is negligible.



Figure 2: Switching perspectives while programming using the desktop version



In previous studies conducted with the desktop programming interface, away from the robot and its physical environment, the integration between the symbolic description of the expected behavior and its physical instantiation was constructed iteratively in the programmer's mind, in a process marked with spatial and temporal delays between the two. In mobile programming these delays disappear, and moreover, the spatial perspectives become unified - the programmer can enact the robot's behavior while programming "in situ", where the action takes place. This brings as close as possible the three components of the symbolic-concrete dialog: playing the robot, describing its desired behavior with symbols and following its actual behavior (Fig. 3).



Figure 3: Using Kinderbot mobile

### 3.2 Theme two - changes in foci and learning patterns in different programming modes

The desktop and mobile modes of Kinderbot share the same logic and structure, yet several differences were noted in the ways in which the programming was carried out by programmers on the different platforms. Following is a comparison of children's performances in the three basic modes of programming between the platforms.

#### 3.2.1 Programming mode one: Immediate execution command-by-command

The first programming mode allows the learner to get acquainted with the basic robot-controlling commands. The four controls introduced in this mode are simple manipulation commands, represented by four arrow-shaped icons for "forward", "backward", "turn right" and "turn left" actions (see Figure 1). Each command symbolizes a single step of the robot in the physical world. For example, in order to program the robot to take two steps forward and a step to the left - the commands would be: forward, forward, turn left, forward.

In the desktop platform, this phase is usually quite brief, ending once the programmer has grasped the use of the controllers. For example, the programmer needs to understand that selecting a vertical sign for “up” (↑) on the user interface, will translate into a horizontal step “forward” of the robot in the physical world.

In the mobile version, controlling the robot seems even simpler and more intuitive than in the desktop interface. Overall, the experience of the first mode is quite similar to that of using a remotely controlled vehicle (the tablet functioning as the remote control), an experience that many kindergarten children are already familiar with. The programmer is standing near the programmable robot and has eye contact with it and with the immediate result of running a command. Since the programmer is facing the same direction as the robot, she/he is not required to a change in perspective or a mental visualization of the robot’s navigation - their perspectives are the same (Figure 3 a,b). However, some children capable of maintaining an appropriate mental model of the spatial behavior of the robot, chose to do the programming while sitting in one fixed spot (Figure 3c).

For all children using the mobile platform, the first mode’s stage became extremely brief and was quickly exhausted as the programmers grasped almost immediately the concept of how to control the physical robot and is ready to move on.

### *3.2.2 Mode two: Immediate execution of a sequence of commands.*

During the second programming mode, the programmer is introduced to the notion of sequencing commands. In this phase, similarly to the previous mode, each command is carried out immediately, in real time, so the programmers can view the immediate outcome of their chosen command. In other words, there is no delay between the symbolic action and the physical action. However, unlike the previous mode, each command is stored in an instructions line, forming a visual representation of the sequence performed – this is a program which remains on the screen and can be activated repeatedly.

A sample task in this mode is the one in which the robot must be programmed to navigate a path, while avoiding various obstacles. The navigation sequence is executed immediately, step by step, while being constructed, but it is also being recorded. The program can then be executed, debugged and modified. Thus, the learners experience and experiment with the different commands and their immediate effect on the physical environment, as well as with the idea of constructing a program that can be further executed again and again.

On the desktop platform, the programmers need to continually adjust their perspective while working in the computer screen, to the robot’s perspective. For example, at some point, the programmer’s left may be the robot’s right and vice versa. For a script requiring multiple steps, they also should be able to estimate the actual distances and the number of steps needed to cover it, given the length of a single step. In addition, given that the robot acts in a concrete physical environment, several factors (e.g., friction, delays) might affect its functioning, generating confusing gaps between the expected (programmed) and the actual behavior. As a result, the programmer using the desktop platform is extensively engaged in cycles of trial and error and debugging.

In the mobile version, since the execution is immediate, there is lesser need for prediction and planning. In addition, less debugging is required as the programmer is effectively following the robot in each step with lesser need to accommodate between the robot’s point of view and her/his own, or to preplan the next move. The result is that this mode (as the previous) is exhausted in a few cycles and the programmers seem to arrive to the next mode sooner. However, the price is that children spend less time handling challenges or engaging in debugging procedures.

### *3.2.3 Mode three: planning and programming a script*

In this phase, the programmer is introduced to preplanning a sequence of commands (a script). Similar to mode two, the objective here is to program the robot to navigate a complex path. However, unlike the previous phase, a sequence of commands will be executed only after a fully program is created and saved. In order to construct the sequence, the programmer is required to use strategies that involve decomposing the problem, reconstructing it modularly, and planning several steps ahead (anticipation). Once the sequence is executed, it may need to be adjusted using different debugging strategies.

In the desktop platform, the progression to this phase is natural while in the mobile platform this mode seems to pose a substantial challenge. We observed that programmers in the mobile platform pass through the first two modes of programming (i.e., initial learning of the controls and initial sequencing of commands) very briefly, as they seem to pose less of a challenge than on the desktop platform. As a result, programmers arrive to the third phase (involving programming of a script) sooner but having spent less time experimenting and developing necessary knowledge. Although not systematically measured by the educational teams in the kindergartens, their observations were that this phase requires more scaffolding on the mobile programming experience in comparison to the desktop experience.

An interesting difference between the desktop and mobile experience relates to debugging. In desktop programming in which the programming environment is spatially detached from the behaving robot, children's main debugging strategy was "replacement": after observing a robot's undesired move, they replaced the instruction causing the (wrong) move by another one. In mobile programming, where the children followed closely the robot's movements, the main strategy was "counterbalancing": not replacing but adding an instruction aimed to correct the wrong move. The result was a sort of continuous "real time" debugging process.

### ***3.3 Theme three - changes in patterns of collaboration among peers while programming***

Teamwork and collaboration processes implicated interesting differences between the two modalities of work. In desktop programming, collaboration between peers developed naturally and was essential, due to the different spatial positioning of the robot and the computer which require a dual perspective. As a result, team work evolves: while one child sits by the computer and enters commands, her/his peers stand by the robot and reports on the outcomes of the commands or programs suggesting further actions. A natural "division of labor" and configuration of complementary perspectives emerge, as one child takes the perspective of the robot while the other takes the one of the programmer. The children arrive to the desired results together, through discussion and collaboration. In addition to the dual perspective collaboration, in some cases two programmers sit jointly by the computer and discuss the programming scenario and issues (e.g., the number of steps or turns needed to complete the task). The navigation track is also often constructed collaboratively by peers discussing its path or the location of obstacles in it. Sometimes the track is built or adjusted dynamically, during the programming session, by several learners in a collaborative process.

Due to the nature of the mobile device, the programming process is more individual in nature. The mobile programming environment is in a handheld, personal device and it is not well suited for manipulation by more than one person. In addition, unlike the desktop scenario described above, the person holding the mobile programming environment stand by herself/himself just with the robot, following its behavior and grasping in real time the bugs to be fixed. However, some forms of collaboration emerge, as other children wish to be involved and actively look for ways to contribute. Most of the collaboration on the mobile mode revolves around the construction of the navigation track for the robot; children participate by adding obstacles, preparing signs (beginning, end etc.) and discussing potential scenarios for enhancing the track (Figure 3d).

## **4. CONCLUDING REMARKS**

The interaction with technology allows kindergarten children to be engaged in technological thinking and to construct a solid basis for the development of complex ideas, through direct manipulation of physical objects (Levy & Mioduser, 2010). The programming environment scaffolds this learning experience by providing tools to think and experiment with. Originally designed as a desktop environment, a mobile version has been recently developed and implemented. The initial findings from the comparison between the desktop and mobile experiences outline key themes that should serve as basis for further systematic research.

The emotional aspects of using the mobile based programming environment should also be further explored. The use of mobile devices creates a new kind of intimacy (Belk, 2013; Turkle, 2008) and further research should explore the implications of the apparent closeness between child and robot. For example, past studies on the desktop environment, found that after some engagement with the robot, children develop a technological -as opposed to an intentional-psychological- perspective towards the robot and relate to the robot as a technical construct and not as an entity with personal will or wish (Ackermann, 1991; Kuperman & Mioduser, 2012).

The mobile, often dubbed as an extension of the self, minimizes the physical distance and separation between the child and robot and this may affect her/his perception of the robot.

Although beyond the scope of this paper, we are aware that the advanced phases of programming as well, dealing with rule and adaptive behavior based on incoming data (via the sensors) should also be examined in depth. Reaching a deeper understanding of the different aspects of the mobile programming experience, may contribute to the design of environments that make use of the unique affordances of the mobile device.

The results of this preliminary study have practical implications as well. The mobile version of the robotic environment is currently in use by several kindergartens in our project. Many of the reported observations will serve as basis for the further design of tasks emphasizing the unique opportunities afforded by the mobile modality.

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# Learning Science and Technology from Play in Early Childhood Education

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This study elaborates educational design principles for teaching science and technology in early childhood education. A model of how children learn science and technology in early childhood education is developed from literature. ‘Play’, in the form of role play and simulating job situations in science and engineering, is an important characteristic of the model. At several early childhood education settings pre-school day care, Kindergarten and Grade 1, professional learning communities were formed to develop and implement educational activities and reflect on the outcomes. Seven conjectures are presented that explain problems and suggest strategies for educational design. Replace this text with your abstract. The abstract should be no longer than 300 words. The abstract should provide an overview of the full paper and should highlight the contribution which is made to the relevant body of knowledge. The font type style should be Times New Roman, size 10, with single line spacing. A 0.5in or 1.27cm indentation should be placed on both left and right sides of the text. The abstract which was accepted for the conference can be pasted in to this section and formatted appropriately.

*Key Words: Early childhood education; Learning from play; STEM education.*

## 1. INTRODUCTION

### *1.1. Aspirations of young people for science and technology*

In many OECD countries, less young people aspire to become an engineer or a technician than there are vacancies. This worries not only people in business but also politicians, since modern-day society relies heavily on science and technology and old and new technologies impact the life of all citizens (European Commission, 2015). New technological professions are emerging (cf. Susskind & Susskind, 2015; Kelly, 2016) that might well suit young people’s aspirations, if only they would new. However, many young people’s choices are influenced by a rather negative, stereotyped, incomplete and outdated representation of jobs in this area and of perceptions that science and technology is difficult and not connected to everyday life (cf. Aspires, 2013; Potvin & Hasni, 2014; Ardies, 2015). Attempts to redress this often focus on ‘end-of-pipe’ solutions, at the moment when young adults choose which professional or academic degree programs and careers to pursue after secondary school. Although this is a valid approach, it may not have a significant effect, since many teachers and schools communicate another, less inspiring message. Research indicates that children, especially girls, can close their minds to science and technology early in life, often under the influence of parents and teachers who do not have a positive attitude towards science and technology (Turner & Ireson, 2010; Van Aalderen-Smeets & Walma van der Molen, 2013; Van Tuijl, Walma van der Molen & Grol, 2014; Corneliusson, 2014)). The challenge thus is to start at an early age and to achieve a positive instead of a negative attitude towards science and technology.

### *1.2. Science and technology in the Netherlands in primary education*

In this study, we focus on early childhood education in the Netherlands with respect to both science and technology, since in the Dutch foundation and primary curriculum these domains are not separated into different subjects. In the Netherlands, the starting situation is challenging. The percentage of students that enrol in higher academic or vocational degree programs related to science and technology is 25%, which is considerably lower than the OECD average of 40% (Techniekpact, 2016). Queries conducted by TIMSS

(Meelissen et al., 2012) and the Netherlands Inspectorate of Education (2017) indicate that the amount of teaching time devoted to science and technology in primary schools is about 4%, compared to 10% as the average in OECD countries. 13% of teachers never engage in hands-on science and technology activities. Inquiry- or design-based teaching pedagogies are employed by only 5% of teachers. This last number is important, since the science and technology core objectives explicitly stimulate primary education to develop skills for design and for inquiry, whereas there is little stress on development of knowledge and concepts (see Table 1). Unlike many other countries, the Netherlands does not have a predetermined curriculum with mandatory topics to be taught or certain concepts to be developed. The core objectives tend to be broad and generic, allowing schools the freedom to make their own specific choices.

*Table 1. Core objectives of Dutch primary education (Greven & Letschert, 2006)*

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<i>42 The pupils learn to investigate materials and physical phenomena, such as light, sound, electricity, power, magnetism, and temperature.</i>
<i>44 Concerning products from their own environment, the pupils learn to find connections between form, material use, and the way things work.</i>
<i>45 The pupils learn to design, realise and evaluate solutions for technical problems.</i>

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Since science and technology is not included in the national testing system and was until recently not a topic for assessment of the quality of schools by the governmental agency for this (the Netherlands Inspectorate of Education), little data are available on what is done and on what is achieved. However, comparative studies such as PISA and TIMSS reveal that cognitive performance of Dutch students is in constant decline, which was recently confirmed in an official report on the state of Dutch education by the Netherlands Inspectorate of Education (2018). Notwithstanding these problems, there is considerable enthusiasm and support in primary schools for strengthening science and technology. In 2013, a so-called Technology Pact was signed by representatives of government, business and education, in which primary education expressed the intention to implement science and technology by 2020 (Techniekpact, 2016). Most schools and teachers back this intention, but they also point to difficulties with transforming the current curricular freedom into concrete outcomes in a domain in which many teachers feel very insecure (cf. AVS, 2017).

This information pertains to primary schools. No such information with respect to science and technology is available for day care, but it is known that professionals working in day care and Kindergarten in general have a ‘non-tech’ mentality (YoungWorks, 2016). There is little reason to expect that science and technology have a more significant place in pre-school day care settings than in primary schools.

### ***1.3. Context and aim of this study***

Windesheim Flevoland is a recently (2010) established University of Applied Science near Amsterdam, in a reclaimed land area that was the ‘bottom of the sea’ until the nineteen sixties. It has a Bachelor’s Degree program for teaching in primary education. In 2018, a new Associate Degree program for educational professionals in day care and in schools will take off. These programs should be informed by practice-based research. In order to improve the current situation sketched above and allow children, in the long run, to make career choices based on personal and valid experiences with science and technology instead of on incomplete representations or prejudice, we started an educational development and research project called ‘Learning from play’, for which we received a grant from the Netherlands Organization for Scientific Research (NWO SIA-RAAK). We furthermore cooperate with the College for Vocational Education of Amsterdam and Flevoland. This College runs the Vocational Degree programs that prepare for professions in day care institutions and schools. Research and development started in February 2017 and will continue till 2022.

The aim of this study is to elaborate conjectures for educational design principles (McKenney & Reeves, 2012) that inform the development and implementation of effective approaches, lessons and curricula for early childhood science and technology education and that can also be used in pre-service and in-service professional and vocational degree programs for schools and day care.

## 2. METHODOLOGY

In this study, we focus on the possibilities for devoting more time and attention to science and technology and for developing a more positive attitude towards science and technology to children age 3 to 7 in pre-school day care settings, Kindergarten and Grade 1 in the Netherlands (in the Netherlands, Kindergarten is part of primary education and almost all children go to primary school at age 4). The research focuses especially on settings in which pre-school day care is organized and conducted in close cooperation with primary education. This is not usually the case, since day care in the Netherlands is private enterprise whereas schools are publicly funded, which complicates cooperation.

In this study, the methodology of Educational Design Research is employed. This is ‘a genre of research in which the iterative development of solutions to practical and complex educational problems also provides the context for empirical investigation, which yields theoretical understanding that can inform the work of others’ (McKenney & Reeves, 2012, p.7). Educational design principles or strategies can take the form of a formula: ‘In an educational Context C Strategies S are expected to result in Outcomes O because of theoretical and empirical Arguments A’.

In order to ground the educational design principles or strategies in theory, a literature search was conducted on science and technology education in the early years. We also included ‘play’ as an important theoretical term, since play is seen by many as the dominant way through which young children develop. From literature (Thelen & Smith, 1994; Gibson & Pick, 2002; Beatty, 2005; Smith & Gasser, 2005; Siraj-Blatchford, 2009; Lillard, Pinkham & Smith, 2010; Kuhn, 2010; Nucci & Gingo, 2010; Van Cleynenbreugel, De Winter, Buyse & Laevers, 2011; Hopf, 2012; Van Oers, 2013; Wood, 2013; Brooker, Blaise & Edwards, 2014; Taguchi, 2014; Van Keulen & Oosterheert, 2016; Van der Graaf, 2017; Van Keulen, 2017; Montes, Van Dijk, Ruche-Navarro & Van Geert, 2018), a preliminary model of how children learn science and technology in early childhood education was developed:

Young children primarily learn science and technology from material objects and phenomena that draw their attention, provoke their curiosity and lead them to engage physically with these objects and phenomena through exploration and the use of their senses (‘action and perception’). Children increasingly test their initial understanding of these objects and phenomena through simulations and role play, in which they try to engage with the objects and phenomena in situations that are meaningful to them and in which the objects and phenomena make sense. These meaningful situations are often scenarios derived from daily life experiences. Interaction with other children and with adults enhances learning considerably. These others are often necessary to complement the scenario and the input of these others, especially adults, can help children to deepen their understanding. The engagement with material objects and phenomena may afford learning outcomes in many other areas important for children’s cognitive and social-emotional development, such as language skills, mathematics skills, social and communication skills and executive functioning, which in turn are beneficial for learning science and technology. A positive attitude for science and technology results from positive experiences, such as pleasure, pride, identification, autonomy, involvement, understanding and mastery.

As a consequence, because of these theoretical arguments, educational design principles should elaborate the characteristics of the material objects and phenomena, the characteristics of daily life experiences, the characteristics of play, and the characteristics of interaction with peers and with adults.

In order to ground the educational design principles empirically in educational practice, we established 16 sites for research at schools and day care institutions in six municipalities in four different provinces in the middle, East and North of the Netherlands. Although these settings were not randomly selected (they volunteered to participate in the research), there is enough variation in the sample with respect to the average social economic status of children, the urban versus rural character of the environment, and the denomination of the organisations (religious versus non-religious) to conjecture that the Dutch educational situation is fairly represented.

In each of the six municipalities we established a professional learning community (PLC) (cf. Pareja Roblin et al., 2014; Stoll, 2015). A PLC in this project consists of the educational professionals and a researcher. Each team gathered nine times and developed in mutual cooperation new lessons, activities, and/or teaching materials, implements these, reflects on the outcomes and, when appropriate, improves the material in a new cycle of development, implementation and reflection.

The aim of the educational design activities was to develop play scenarios, preferably derived from science and technology contexts such as job situation that are meaningful to the children, in which children apply (and improve) their executive functions to keep the play going, in which they interact with each other and with their teachers, and in which cognitive development with respect to science and technology (such as the development of skills for exploration, design and inquiry and conceptual understanding of natural and technological phenomena) and with respect to language and mathematics are explicitly fostered.

Empirical data collection focused on the characteristics of the activities and materials developed and implemented and on the development of the professionals themselves. For this, discourse in the PLCs was recorded in the form of written narratives by participants and the activities with the children were observed. Many other data (for instance, on teacher efficacy, on children's involvement, on vocabulary development) were also collected but for reasons of space we elaborate the results that pertain to the activities and the development of the professionals.

### 3. RESULTS

In this stage of the project, all findings are preliminary. Space does not permit to describe observations, available data and other experiences in full detail. We confine ourselves to presentation of the initial results, which take the form of two sets of conjectures: one to explain problems and one to predict design principles and strategies (Cobb & Gravemeijer, 2008).

#### 3.1. Conjectures for problems

This set conjectures the explanations and possible remedies for non-trivial problems that arose during the development and implementation of the educational materials. Obviously, the project aims to achieve ambitious goals with professionals who may well be underprepared for this.

*Conjecture 1: It can be expected that early childhood professionals have little knowledge of and experience with science and technology.*

The professionals in our sample do use objects and phenomena from the natural and technological world as a source of inspiration for educational activities, but not with a focus on developing children's understanding of the material world and/or developing their technological design and problem-solving skills. It is more important to them that children 'have fun' than that they learn to understand the world. For example, they choose 'Autumn' as a theme rather than 'Building a bridge'.

A possible strategy for improvement: Professionals need considerable support in the form of ideas for activities and resources and help with content knowledge development, for instance through cooperation with technological enterprises and professionals.

*Conjecture 2: It can be expected that the professionals' conception of 'play' is dominated by the notion of 'free play'.*

In free play, professionals focus on maintaining safety, but do not interfere much, certainly not when children appear to be happy. For instance, they initiate but do not play along. Reflections of professionals reveal that they find it difficult how to play along. This limits the educational process quality of their interaction (cf. Pianta, Paro & Hamre, 2008; Slot, Mulder & Leseman, 2014). Their contribution to conceptual or skills development in the area of science and technology is limited, as well as their contribution to the development of vocabulary and mathematics skills.

Strategy for improvement: Professionals need to develop richer conceptions of play, especially simulation play and role play. They need to expand their repertoire for interacting with children.

*Conjecture 3: It can be expected that professionals' conception of 'learning' is dominated by the direct instruction model of teaching and learning.*

On the one hand, all professionals state that children learn a lot from play. On the other hand, they do not seem to believe this. 'Real learning', so they say in interviews, starts in Grade 1 and is totally different from play:



children will sit in rows behind tables and work with paper and pencil on work sheets, with the teacher in the role of the instructor. As a consequence, the executive skills that children do develop in day care settings and Kindergarten to regulate what they do and learn while playing become rather useless from Grade 1 onwards. Also, children's developing skills for inquiry and design, initiated by playful explorations of the material world, receives no follow-up in Grade 1 and onwards.

Strategy for improvement: Professionals should learn to see 'play' as an educational strategy for the attainment of learning objectives that are important in school. They should learn to help focus children's executive skills on the regulation of these learning processes and not (just) on the regulation of aspects that are external to learning, such as 'choosing the activity' and 'tidying up when ready'.

### **3.2. Conjectures for principles and strategies**

This second set conjectures the educational design principles and strategies that can be put to further empirical testing in subsequent curriculum development for pre-service and in-service professional development and degree programs and for the development of lessons by the educational professionals themselves.

*Conjecture 4: Children's play can be modelled after well-known technological professions.*

Children like to play out scenarios that they encounter in their daily life. It is their way to prepare for roles in adult life. An important objective of education is to prepare children for participation in society, which also means improving their chances to find a job. Many technological vocations and scenarios are meaningful to young children because they fulfil needs the children themselves have and recognize. Examples are 'running a pancake restaurant'; 'building a bridge'; 'selling construction material at a do-it-yourself store'; 'making a pair of blue jeans'. Meaningfulness to children thus is a heuristic for finding sources of inspiration for play and for finding the right partners outside school to cooperate with.

*Conjecture 5: Differences in material affordances can be used to develop differences in role play and, consequently, differences in executive functions.*

Children need to develop various executive functions, such as attention, cognitive flexibility, inhibition of impulses, control of emotions, working memory and planning to regulate what they are doing. Different materials and phenomena afford different perceptions and actions and allow for variation in the development of executive functions. For instance, when children play that they work in construction and build a house with wooden blocks, chances are that their construction will collapse within minutes. Concentration is priority. Actions have to be carefully controlled and impulsive movements should be suppressed. The collapse can lead to outbursts of emotions. Contrast this with playing a gardener who is growing cress. Change in this scenario is not on a minute-to-minute scale. You just should not forget to water the plants every day. Playing a gardener appeals on planning and the ability to load the appropriate actions to working memory.

*Conjecture 6: Play-for-learning in the form of Simulation-of-Technological-Jobs can accommodate many functional activities related to language and mathematics development.*

When children play that they run a pancake restaurant, there are many opportunities to learn science and technology, but there are as many opportunities to develop language and mathematics skills. For instance, a restaurant needs a menu, which has to be written. Customers have to pay, which means calculating the bill. Recipes have to be developed or changed, et cetera. Many of these language and mathematics skills can be contextualized and for professionals who are able to design and implement play-for-learning there is less need to fall back on the methodical but scholastic direct instruction model. Pre-service and in-service professional development programs can help early childhood education settings with expanding the pedagogical repertoire, to include scaffolding techniques (Mercer, Dawes, Wegeriff & Sams, 2004), of inquiry and design-based teaching (Lazonder & Harmsen, 2014; Van Heerden, 2014) and content knowledge (Henrichs & Leseman, 2014).

*Conjecture 7: Children learn more from play when they can interact with experienced adults.*

In play, children try to behave as adults. They are wide open to input from those who play along and have more experience and a larger vocabulary. Professionals in day care and Kindergarten should put their existing knowledge of science and technology to good use (for example, on how to prepare cupcakes, mend a flat tire or sew clothes) by playing along, explicating what there is to be seen, and by challenging children with questions and observations. They can increase their knowledge the same way as children learn, by engaging in

professions they are less familiar with, talking to engineers and technicians, observing and appreciating their work routines and in this way expand their own vocabulary and self-efficacy (cf. Sennet, 2009; Madhavan, 2015). Pre-service and in-service professional development programs can help early childhood education settings with organizing this.

#### **4. DISCUSSION**

This research and innovation project has just started, and we are currently satisfied with establishing the first sets of conjectures for what might be an effective approach for early childhood science and technology education, and what might be explanations for non-trivial and recurring problems. The situation in the Netherlands is peculiar in the sense that there is no mandatory curriculum for the foundation years or primary education. The educational system relies on core objectives which are rather broad and generic. There is an explicit focus on developing skills for inquiry and design, but these are not assessed in any systematic way. This means that on the one hand, this gives schools and teachers much freedom but on the other hand, effort put into science and technology education or in professional development with respect to science and technology content knowledge or pedagogical skills for inquiry and design-based teaching, is not rewarded by the system.

This project is highly ambitious in its attempt to affect enrolment in science and engineering jobs through early childhood education. It will be difficult, if not impossible, to establish a causal link between intervention and effect. Conceptually, it relies on the assumption that attitudes are formed early in life and can be influenced. In the long run, we hope that it will become self-evident that working in early childhood education implies a positive attitude for science and technology and self-efficacy with respect to teaching through science and technology. It may be possible to investigate this hypothesis in the future.

The insights developed in this study are qualitative rather than statistically significant in nature and come from a limited set of locations. Although the early childhood locations and professionals that are involved in this project are not randomly selected, they are diverse, and, in our view, they represent early childhood education in the Netherlands rather well. However, new and better insights may develop when more educational designs have been put to the test at these and other locations.

Young children may be even more curious than scientists or engineers, but their abilities for systematic inquiry and design have yet to be developed (cf. Kuhn, 2010). We do not know whether this development is linear and smooth, or whether it requires substantial cognitive leaps. Several Piaget-like stages may be conjectured. Perception and (initially random) action is the approach of babies (Baillargeon, Li, Gertner & Wu, 2010). Toddlers explore wilfully, but don't argue, reflect or present consistently (Gelman & Frazier, 2012). In Kindergarten, children seem to be able to test hypotheses and vary only one parameter at a time (Van der Graaf, 2017). When exactly children are able to move consciously through the steps of a design or inquiry cycle is not known, and neither do we know how this development correlates with 'nature' (age or talent) and 'nurture' (exposure to good quality teaching). This would be interesting to investigate in more detail.

Last but not least, a lot of work remains to be done with respect to analysing jobs and professional situations in science and technology with respect to their learning potential. This is a fascinating enterprise. Close cooperation between early childhood education centres and the scientific and technological practices and business in the direct environment may strengthen local communities and prepares children for participation. Such an approach is reminiscent of the medieval guild system (cf. Sennett, 2009) but in a modern, flexible guise.

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# STEM in Northern Ireland Primary Schools: Where is it at, and where should it go?

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The aim of this research was to record the pupils' voice regarding how STEM education should be developed within the Primary Schools of Northern Ireland, but alongside the voices of those in positions to significantly impact upon the pupils' experiences. As Benson and Lunt (2011) point out, there is a lack of the pupils' voice within literature and it is important that it be listened to and acted upon: 'Children naturally have very important insights to offer in helping us to develop our understanding of teaching and learning.' The principal objective was to film an 'Academic Documentary' to constitute both a methodology for data collection and a medium for dissemination. Pupils were interviewed within small groups, while adults were interviewed individually. Key findings from the pupils were the relevance and importance they attributed to STEM education, together with the enthusiasm with which they engaged with STEM experiences; from the adults, key findings were the critical need for training, the need for societal value of practical skills, the consensus that STEM education should be problem-based and compulsory, the need for effective transition, and the need for a more effective coalition with business. The current study is considered important as there has been no previous research of this kind carried out in Northern Ireland.

## 1. INTRODUCTION

The vision for the future in relation to Science, Technology, Engineering and Mathematics (STEM) education in Northern Ireland (NI) was articulated by the Report of the STEM Review (NI Departments of Employment and Learning (DEL), and of Education (DE), 2009, p11) as, "Empowering future generations through science, technology and mathematics to grow a dynamic economy". The report (p11) made 20 recommendations, which were listed under four major headings:

1. Business must take a lead in promoting STEM
2. We must alleviate key constraints in the STEM artery
3. There needs to be increased flexibility in the provision of STEM education
4. Government must better coordinate its support for STEM

There has been much written about the importance of STEM education in relation to both the individual education of pupils and the benefit that may accrue to countries' economic performances, by virtue of having more STEM graduates in the future (DE, 2012). However, Bybee (2010, p30) has articulated the possible confusion that exists about the term when arguing that, "Once again, the education community has embraced a slogan without really taking the time to clarify what the term might mean when applied beyond a general label". Brown et al. (2011) also contend that as the notion of STEM education gains traction there is a need to more clearly define what is actually meant by the term.

There are three possible basic curricular strategies that can be applied to the teaching of STEM subjects in school: the silo, embedded and integrated. The silo approach is to teach each individual STEM subject in isolation from the other constituent subjects. The disadvantage to this approach is that pupils fail to see the natural integration that occurs between STEM subjects in the 'real world' (Breiner et al. 2012). The embedded approach is where the specialist knowledge of one of the STEM disciplines is placed or taught within the

context of another (Rossouw et al. 2011) e.g. science within the context of technology or mathematics. There is however a danger with the embedded approach that the learning can become fragmented (Novack, 2002). The integrated approach to STEM education necessitates the teaching of the STEM content across the various disciplines as one subject. It is suggested by some that the integrated approach best reflects the reality of how STEM concepts are utilised (Dixon and Brown 2012; Morrison and Barlett 2009; Sanders 2009). Wang et al. (2011) suggest that there are two approaches to integrated STEM education: multidisciplinary and interdisciplinary (also referred to as 'transdisciplinary' by Vasquez (2015)). The multidisciplinary approach involves the subjects being taught separately but with the connections being made during the teaching. Interdisciplinary integration on the other hand concentrates on a problem whilst bringing together the content and skills from the various subject domains. However, it is also contended that an integrated approach can lead to the integrity of the individual STEM subjects being undermined (Williams, 2011; Harden, 2000). Barlex and Pitt (2000) are also not convinced of the merits of attempting to merge the teaching of Science and Technology, insisting that any attempt to do so, due to their significant differences, would be both, "illogical and highly dangerous". Williams (2011, p32) argues that, "Rather than integration, a more reasonable approach may be to develop interaction between STEM subjects by fostering cross-curricular links in a context where the integrity of each subject remains respected".

An integral part of this research was to listen to what the pupils had to say about STEM in terms of what they had experienced to date and what they would like to experience in the future. Indeed, as Benson and Lunt (2011) point out, there is a lack of pupils' voice in the literature more broadly. They further argue that, "Children naturally have very particular and important insights to offer in helping us to develop our understanding of teaching and learning" (p697). McNair and Clarke (2007) also suggested that it was necessary to listen and act upon pupils' feedback on STEM-based oriented problem-solving tasks, which have been designed for the purposes of enhancing their understanding of the constantly changing man-made world in which they live.

The aim of this research is therefore to record the pupils' voice regarding how STEM Education should be developed within the Primary Schools of Northern Ireland, but alongside the voices of those in positions to significantly impact upon the pupils' experiences.

## **2. METHODOLOGY**

The use of questionnaires was judged to be unlikely to provide the richness of data that could be gained through interviews where, for example, nuances can be picked up and responses can be followed up. Seidman (2013) and Peraklyia and Russuvuori (2011) argue that the purpose of interviewing is to understand the experience that people have in life along with the meaning that they take out of that experience. This is exactly the rationale that was applied to the selection of interviews as the primary data gathering tool within this study i.e. the purpose was to find out the meaning that pupils made of their experience of engaging in both the normal school based practical work and authentic problem solving tasks that had links with industry, and crucially, the issues that they, unprompted, wish to identify within these experiences.

Face-to-face interviews can be conducted one-to-one or in groups. In the case of the latter, Cohen et al. (2011) draw a distinction between 'group interviews' and 'focus group interviews'. In group interviews, as in one-to-one interviews, they consider the object is the gathering of data on the views of the individual. In focus group interviews, interaction among participants is deliberately fostered. They argue that whereas focus groups rely on interaction within the group, group interviews are more about interaction between the interviewer and individual members of the group. They further indicate that whilst interviewing young people individually is valuable, group interviews also have merit. In this study, then, 'group interviews' in the sense used by Cohen et al. (2011) were adopted, which also allowed pupils to derive some peer comfort from each other's presence, whilst at the same time avoiding problems associated with bigger group interviews, such as non-participation.

The particular approach used within this study focused upon filming the semi-structured interview. It was reasonably anticipated that the relative dynamics of group interviews (Cohen et al., 2011), and the advantages of interviews detailed by Seidman (2013) would similarly apply to the use of video recording, as opposed to the more established media of voice recording or transcription. However, a grounded theory approach was

maintained, with conceptualisations derived from the gathered data, and thematically coded, and analysed. Therefore, it was also anticipated that video recording would support this style of theory development by rooting it more explicitly within empirical investigation, and with more immediate and unfiltered access, to ensure that the outcomes would maintain relevance. Video outcomes would, of necessity, be edited, but this is to filter merely the quantity and not the quality of access to empirical data. It was further hoped that video recording would support Glaser's post-positivist approach, whereby, with reference to data interpretation, awareness would be maintained of the limitations of certainty (Glaser, 1999).

In order to capture the pupils' voice regarding how STEM Education should be developed within the Primary Schools of NI, a sample of four Belfast Primary Schools was contacted, to equally represent experiences and views for both boys and girls from both the controlled and maintained NI education sectors; rural school input would have ideally been included, but would have been impracticable within the given funding; the schools chosen have all engaged significantly with STEM education and therefore speak from experience; pupils from Primary 7 classes (aged 10 and 11 years) were interviewed to provide the most informed possible assessment at the ends of their Primary School experience; pupils were interviewed within their school groups to remove any distraction or inhibition.

It was considered to be important to capture the voices of those in positions to significantly impact upon the pupils' experiences: individuals represented the two NI university colleges for Teacher Education, along with the NI Assembly for devolved government, a principal author of the NI STEM Report of 2009, a founder and director of the NI Science Park to support local industry and entrepreneurs, the NI Chair of CAS (Computing At Schools), and four Primary 7 teachers from the four participating schools, along with one of the participating school principals; written submissions were also received from two individuals unable to attend the days of filming, one a professor of the Ulster University, and the other a representative of the Institute of Engineering and Technology (IET).

All participants were advised of the intention to compile the recorded interviews to create an 'Academic Documentary' that may be distributed on an academic network, hosted by the Royal Society for the encouragement of Arts, Manufactures and Commerce (RSA). They were advised of the questions and to give some thought in advance to the questions, so that only succinct and key points would be presented. RSA funding secured the services of a professional freelance cameraman and editor of established and experienced industry (BBC and Ulster Television) standard. A filming itinerary was compiled for the first day of filming, which comprised the participant interview recordings. The camera tapes of these recordings were then edited in 'offline' format (to provide approximate camera tape time codes, excerpt selections and excerpt sequence), so that a 'script' addressing introductory and discursive content along with locations could then be written for the second day of filming. The second day comprised recordings of the linking sections between collections of interview data.

Data was held securely, voluntary and informed consents were obtained for all participants, including the right to withdraw without reason; the interviewer was regularly reminded to be careful to provide time for the interviewees to speak and to avoid leading. Participating school principals and teachers were assured of pupil anonymity, and advised that uniforms should not be worn, by which the school could be identified; only pupil Christian names were used at any time. Participating experts were given the option of identifying title captions and credits.

### **3. RESULTS AND DISCUSSION**

Edited interview totals comprised: 64 clips; 21min 20sec; 13 pupils; 11 adult experts. Filmed interview data from participants was open-coded into seven themes:

#### ***3.1 The pupils' voice***

Within the range of schools, pupils spoke of various experiences and perceptions of STEM, with no discernible significant differences between the school experiences. Science and Technology clubs were identified, along with activities including: testing materials; building merry-go-rounds and windmills; solving problems to

ensure their kites would fly; programming using Scratch; a lighthouses project in P2 (aged 5 and 6 years); a Science Week in P6 (aged 9 and 10 years); investigating working boats with propellers; using science kits, such as Connect and Lego; visits from STEM Ambassadors from Bombardier Aircraft Company; an ‘Inspiration Day’ in P6, where people came in to talk about their various jobs; a visitor from ‘Medics in Primary School’ to talk to the pupils about how the human body works.

The pupils also spoke of their perceptions and assessments, which are summarised in Appendix 1.

It is apparent from the pupils’ comments that they had experienced activities that required them to plan and design systems that resulted in practical outcomes, which they could identify as having relevance in their everyday worlds. What was also evident from some of the pupils’ comments was that they had an understanding of how the four subject disciplines making up STEM were interconnected. These pupils were in fact, at their level, applying a multidisciplinary approach, with regards to STEM education, towards solving problems, which was the approach advocated by Williams (2011). It would also seem to have enhanced their appreciation, as described by Hernandez et al (2014) of the interdependent nature of science and mathematics.

And they spoke of their aspirations, which are summarised in Appendix 2. Their comments illustrate how the career aspirations of pupils can be articulated at an early age and lend weight to the argument that a relevant STEM education should be offered during primary education.

### ***3.2 Where to, now?***

One of the principal authors of the NI STEM Report of 2009 identified within the report’s original vision a recognition of the numbers of pupils disengaging from the STEM subjects, but also of the value of STEM within society, to the economy, and also to young people with regard to their careers.

A Member of the NI Legislative Assembly (MLA) agreed that sufficient progress hasn’t been made in implementation of recommendations of the STEM Report. However, he added that in his opinion, much of education still appears to be sedentary, that we need a balance between the academic and the practical, and that many talented people have been deemed to have failed, but actually had a lot to offer; he concluded that we need to match curriculum to different learning models.

These views were echoed by one of the university college principals of Initial Teacher Education (ITE), concluding that in our [NI] society, the premium still rests with academic education and the ‘professions’, and that we need to raise the bar for the place of STEM in our education system, to be more comparable with the societal recognition in Germany. The NI Science Park director went further: he asserted that the current system of education in NI is a memory test, which is not preparing children well for the new world of work, whenever a lot of that memory requirement is automated. He added that the Victorian model of education was designed to produce young people to work in factories and jobs that no longer exist, that it has to evolve, and urgently. These views converge with those of Hernandez et al (2014, p108), who argued that pupils should have opportunities to engage in “authentic experiences to study how things work and how technologies are created”.

### ***3.3 What should it be - cross-curricular, compulsory, problem-based?***

From all of the experts, there was unanimous and unequivocal agreement that STEM should be compulsory, cross-curricular and problem-based: “This is the future, this is where we are going; STEM should be filtering into every area of the curriculum, and perhaps young teachers coming in to the profession are not fully aware of the importance of STEM”.

The NI Science Park director sounded a note of caution, noting that the STEM agenda can be a little bit too powerful, over-riding the need for development of more creativity, collaboration, teamwork and resilience within young people; he was concerned that in the age of automation, if children are not taught how to think and develop more translational skills, they run the risk of becoming obsolete in the new age of work. These views demonstrate the value of having, as the Report of the STEM Review for NI (2009) envisaged, the input of business, where what might be described as work-based values can be included within a STEM education strategy for schools.



### ***3.4 Continuous Professional Development (CPD)***

There was recognition in 2009 that training was needed for Primary School teachers to enable them to introduce the new 'World Around Us' curriculum, which included STEM, but the teachers all reported that there is a complete absence of any training. One of the university college ITE principals countered that dedicated STEM modules would be very difficult to deliver within teacher education, but admitted that it needs to be looked at more carefully. Despite this, the NI Chair of Computing At Schools (CAS) emphasised that the future of STEM education in Primary Schools hinges upon having properly trained teachers and the other university college ITE principal agreed that more teachers and a wider range of professional profile are needed to support the delivery of STEM.

In terms of the training issue, the evidence is overwhelming and clear: the need is critical, but the need has not been met.

### ***3.5 The Role of Business***

From 2009, there was a willingness within business to support STEM in schools, but there wasn't the co-ordination between businesses, schools and universities to make that a reality. As identified by the Primary School principal, Primary Schools want to improve the STEM experience for the children, but are limited by resources – therefore, collaboration and industry partnerships are needed. The need was supported by the MLA, adding that business can show pupils why they're learning what they're learning and the practical applications, and "if we want to keep the businesses we have and attract new business in to NI, we need to provide the skills locally, and that will also be good for the prospects of the pupils". The NI Chair of CAS was more prescriptive, warning that business leadership of STEM in education should be cautioned, that business may have expertise in subject content, but the Teacher Education departments in universities would be needed to combine subject knowledge with the pedagogical knowledge and language that would be essential for successful integration of business/industry and schools.

The latter point may be assessed to be of much significance: that business may possess the expertise and schools have the need, but there is a missing link, a missing interpreter, a missing part that would be perfectly met by student teachers - that student teachers are an untapped resource and critical link.

### ***3.6 Transition Issues***

Primary School teachers again agreed that only numeracy and literacy have been considered with regard to the Key Stage 2/Key Stage 3 transition; "there hasn't been a mention of STEM". Significantly, it was highlighted that a successfully working model for good practice with respect to transition planning already exists, but again, it hasn't been applied to the STEM subjects. There is a clearly evident frustration about transition issues: the solution is already successfully in operation, but where it is applied, it is applied only to literacy and numeracy, and not STEM.

### ***3.7 Pupil Voice.... as voiced by the adults***

As reinforced by the MLA, from Article 12 of United Nations Convention on the Rights of the Child, children should have a say in all decisions affecting their lives. Therefore, there is both a moral duty and statutory obligation, but, "in NI, we haven't done well enough in listening to children's voices". These sentiments were echoed by both of the ITE university principals: "We have to start from the premise that the pupils own their learning – they are the ones who are growing up in to the world that we do not know"; "We have boxed people in to a particular view of science and the arts, where children don't differentiate....we have an obligation not to dismiss the learner, but to become a more effective educator, because we have listened to the learner....."

## **4. CONCLUSION**

What was clearly demonstrated as a result of this research was the enthusiasm that the pupils had for a STEM-based education that allowed them to be creative, solve problems and relate the outcomes of their activities to the world around them. The pupils appear to understand the relevance of a STEM education to their ongoing

development and how it might enable them to meet their future career aspirations. The pupils' teachers and the ITE principals were also in agreement that the pupils' voices they had heard were articulating a strong desire for the inclusion of STEM education within the curriculum and that this was based on both the educational benefits and enjoyment that they had gained thus far from taking part in STEM-based problem-solving oriented activities. The teachers and the ITE principals were also in agreement that STEM education should, in principle, be compulsory within the NI Curriculum and within considerations for Key stage transition. There was an acknowledgement however that this would need careful planning and implementation in order for it be effective; this would also apply to a meaningful provision being made for the continuous professional development of teachers in relation to STEM education. The views of business are also important, although these cannot simply be implemented without an in-depth review of the pedagogical strategies that would be necessary for successful implementation within a school setting. There was accord that STEM subjects should be more valued within society, perhaps within a review of the effectiveness of the current education system's preparation of children for the changing world of work.

Finally, and perhaps most problematic of all given the present political impasse in Northern Ireland, the government must give effect to the changes that are required in order that an effective STEM education may be provided for the young people of Northern Ireland.

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## 6. Appendix

### APPENDIX 1: PUPIL PERCEPTIONS AND ASSESSMENTS

‘...we get to observe and do it with our hands – it’s physical and practical’;

‘We’ve been observing and we’ve been discovering, and we’ve been planning designs, and we learn from our mistakes’;

[of building robots using Lego] ‘it’s really hard to do, and if I build it, I’ll feel proud of myself’;

‘It [STEM] seeps in to every job that people are doing, jobs that will become – and it just helps the world evolve...the jobs that you will get paid for are the more complex jobs...Science makes up everything, Technology’s going to be the future, Engineering’s going to build the technology to be the future, and Maths. is going to solve it’;

[to become an Oceanographer] ‘Science is quite an obvious one, specifically if you want to be a Biological Oceanographer; technology is good for recording what you’ve learned about the ocean, and then that also ties in with Mathematics, because you’d need a good sense of mathematics to do a lot of Technology things, and then Engineering – you need to do – a lot of – emmm.....’;

‘for Engineering, it would be interesting to learn how to fix vehicles...it would also be interesting to learn about structures built by engineers...for Mathematics, we learn a lot about it, but we would also like to learn to use our skills in the real world’.

### APPENDIX 2: PUPIL ASPIRATIONS

‘I would like to be an architect - they design buildings and plan so the engineers can build them’;

‘I want to be, like, an engineer – like a car engineer – they fix cars and they can make them better’;

‘I’d like to become an engineer, maybe an astro-engineer, and I’d like to expand from this world to another one until we’ve met everything that we can achieve....’

# STEM Associational Fluency: The Cross-Training of Elementary and Middle Grade Math, Science, and Engineering Pre-Service Teachers

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The integrated approach to STEM education (iSTEM) includes instructional approaches and complex classroom interventions that interweave content and learning experiences among and between any of the STEM subjects or other school subjects. While learning-in-doing through integrated design problems situates the learner to apply the “thinking tools” from varied STEM knowledge structures, e.g. mathematics or physics principles on demand when needed. This STEM “associational fluency”, where students thinking crosses content borders begins to mirror expert engineering practice. Prior research conducted by the authors with students indicates that they often view science, technology, engineering, and mathematics as separate fields, and thus perceive relatively low levels of integration across STEM disciplines. However, prior research among high school students indicates that engaging in classroom-based projects that vertically and horizontally integrate applications of the math, science, and engineering improve students’ appreciation and connection of the integrated contents of STEM disciplines. This research reports on a new line of inquiry followed by the researchers on the cross-training of pre-service teachers to acquire a new element of Pedagogical Content Knowledge (PCK) we term “STEM Associational Fluency”. The report on research conducted examines the methodological and measurement challenges associated with research associated with PCK and will share the initial results of the intervention on pre-service teachers.

*Key Words: STEM, Engineering Design, Inquiry, Pedagogy.*

## 1. INTRODUCTION

The Next Generation Science Standards (NGSS) articulates a broad set of expectations for students in science grounded in practices and inquiry. Within these guiding standards are three major dimensions around which grades K-12 science education needs to be integrated into standards, curriculum, instruction, and assessment. These dimensions include: a) scientific and engineering practices; b) crosscutting concepts that unify the study of science and engineering through their common application across fields; c) and core ideas in four disciplinary areas: physical sciences, life sciences, earth and space sciences, and engineering, technology, and applications of science (NGSS, 2013). Integrating the three dimensions now includes the addition of engineering, technology, and applications of science. Realizing the full potential of the NGSS will require new conceptions of learning and instruction being adopted to include the richness of unifying practice, inquiry, and design across STEM concepts and contexts. Integrating the three dimensions could prove elusive, however approaches informed by research on teaching and learning from cognitive sciences combined with aggressive methodological approaches to measuring student learning within the three dimensions may yield promising results.

## 2. LITERATURE REVIEW

The conceptualization and design of this study is informed by two perspectives; the first influenced from well researched areas of teaching and learning from the cognitive sciences; and second from the newly released NGSS (2013). The consonance between models of classroom learning and teaching are informed by research from the cognitive sciences and the new frameworks vision to actively engage students in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields.

One approach to this transformation process can be addressed through adopting well-researched approaches to learning and instruction grounded in the cognitive sciences. An example of this has been evidenced with the emergence of engineering and technology education as an integral component of STEM education. Today's engineering and technology education originated without any meaningful input from cognitive science research. However, it appears that engineering and technology education practices advocated in the new K-12 science education framework are remarkably consonant with findings from cognitive science that defines good instruction (de Miranda, 2004). Additionally, the American Society of Engineering Education (ASEE) has continually promoted the notion that, engineering design, by its very nature, is a pedagogical strategy that promotes learning across disciplines (Roozenberg & Cross, 1991). This approach allows students to explore mathematics and science in more personalized context while helping them to develop the critical thinking and reflection skills that can be applied to all facets of their work and academic lives.

### **2.1 STEM Associational Fluency**

The integrated approach to STEM education (iSTEM) includes instructional approaches and complex classroom interventions that interweave content and learning experiences among and between any of the STEM subjects or other school subjects. Cognitively, this leads to STEM "associational fluency" in which a pre-service teacher, and eventually the classroom teacher, can look at any given problem or project in one subject area and easily make content and context connections to other STEM subject areas, creating an opportunity for the students to not just work on one project in isolation from other subjects, but instead as in integrated project that combines one or several other STEM areas. In students, this is characterized as STEM "associational fluency", where students thinking crosses content borders and begins to mirror expert engineering thinking and practice. Prior research with students indicates that they often view science, technology, engineering, and mathematics as separate fields, and thus perceive relatively low levels of integration across STEM disciplines (Hernandez et al., 2013). However, research among high school students indicates that engaging in classroom-based projects that vertically and horizontally integrate applications of the math, science, and engineering improve students' appreciation of the integrated nature of STEM disciplines (Hernandez et al., 2013). Furthermore, this research also shows that engaging student in projects that integrate across STEM disciplines is most impactful on those that have relatively low perceptions of the integrated nature of STEM.

Following along these lines, the researchers were interested in how an engineering methods course that integrated both math and science courses, typically conducted separate from each other in teacher education programs, could be used to involve preservice teachers in an activity that would unify practice, inquiry, and design across STEM concepts and contexts, and to understand what benefits, if any, were there to using this type of course design. These led to several research questions:

- 1) Are pre-service teachers able to successfully co-create an engineering design brief that includes cross-cutting concepts from math, science, and engineering standards?
- 2) How would the pre-service students view integrated math and science co-planning activity?
- 3) How would this activity impact the students' self-efficacy, interest or belief in the utility of teaching engineering, math, and science?

## **3. METHODOLOGY USING PRE-SERVICE STUDENTS**

The introduction to engineering methods and design practice took place over 4 weeks, as the course only meets once a week. The assigned project required the use of both math, science and engineering related content. Students formed groups of four in which they would be working as a teacher team. The project required the students to develop an engineering design-based problem for students in a classroom that incorporated both math and science curriculum standards appropriate for the grade-level they chose to work under. After determining their problem idea, students created several artefacts: *i)* contents blueprint; *ii)* design problem brief; *iii)* problem poster; and *iv)* solutions poster.

### **3.1 Participants**

The participants for this study included 66 students in a university senior methods course over two separate semesters at a large predominately white institution (PWI) in the southern United States, located in an urbanized area with several smaller rural towns located within a 30-45 minute drive of the university. Of these participants, 62 were female. 47 of the students identify as White, 15 as Hispanic, 3 as African American, and 1

as Asian. All students were seniors in terms of credit hours and ranged in age from 20 to 30, with a majority of the students being 21 or 22.

### **3.2 Data Collection and Analysis**

Students were asked to complete a pre and post questionnaire about their experience with the engineering design project. 61 of the 66 participants completed the questionnaire. The post-questionnaire included items about their experience with the project, as well as the same interest, utility, and comfortableness questions from the pre-test in order to investigate any changes in these concepts. See Appendix B and C for the pre and post questionnaires. In addition to pre and post questionnaires, the students' final design brief and solutions posters were collected as artifacts to determine how successful the students were at completing the overall project. A scoring rubric previously used for pre-service teacher engineering design problems (Fantz, De Miranda, Siller, 2011) was employed to determine how successful groups were at completing their engineering design projects, and which descriptive analysis was run to understand the overall performance of the students.

Conventional content analysis was used for this study (Hsieh & Shannon, 2005) as existing theory or literature about this style of methods course is limited. Analysis began with reading all data from the questionnaire items repeatedly in order to get a full understanding of the whole picture. Data was read word for word, line by line and coded using the methods published by Saldana (2009). For the quantitative pre and post questions, an independent sample t-test was used to determine if differing results exist.

## **4. RESULTS**

### **4.1. Did the pre-service teachers successfully create Engineering Design Briefs and use the engineering design process to come up with a solution to their problem?**

For this question, the final design posters were scored using a rubric adapted from one developed by the American Society of Microbiology (Annual Biomedical Research Conference for Minority Students, 2013; See Appendix A). The rubric included five variables scored on a scale from 1 (lowest) to 5 (highest): *i*) goals and context; *ii*) design and testing; *iii*) results; *iv*) product and conclusions; and *v*) solution poster aesthetics. Table 1 shows the descriptive statistics for the scoring of these posters.

According to the rubric and the descriptive statistics, the students struggled most with presenting their results ( $M=3.13$ ), the products and conclusions ( $M= 3.53$ ), and the design and testing ( $M=3.53$ ). Figure 1 shows the performance of all groups on each individual measure. For these 17 groups of teachers, design & testing is most highly rated followed by poster presentation. The scores for Product and Conclusion ranged from the lowest score of 1 all the way to 5. On all variables, the mean of all posters scored about the mid-point level of 3. All of the projects except for one scored at or above 60% of the total possible points. Table 1 provides an ordered description of which groups performed best. Table 2 shows the detailed descriptive results of the final design posters.

*Table 1. Individual Groups' overall performance in order of magnitude*

<i>Group no.</i>	<i>Overall Performance</i>
6	23
8	23
1	21
3	21
10	21
14	21
16	21
15	20
12	19
13	19
2	18
5	18
7	17
11	16
4	15
9	14

Table 2. Descriptive Statistics of Scored Final Design Posters

Descriptive Statistics					
	Poster Board	Goals and Background	Design and Testing	Results	Product & Conclusions
Valid	16	16	16	16	16
Missing	0	0	0	0	0
Mean	4.313	4.438	3.563	3.313	3.563
Median	4.500	5.000	4.000	3.000	4.000
Mode	5.000	5.000	4.000	3.000	5.000
Std. Deviation	0.793	0.964	0.512	1.138	1.548

Frequencies ▼					
Frequencies for Poster Board					
Poster Board	Frequency	Percent	Valid Percent	Cumulative Percent	
3	3	18.750	18.750	18.750	
4	5	31.250	31.250	50.000	
5	8	50.000	50.000	100.000	
Missing	0	0.000			
Total	16	100.000			

Frequencies for Goals and Background					
Goals and Background	Frequency	Percent	Valid Percent	Cumulative Percent	
2	1	6.250	6.250	6.250	
3	2	12.500	12.500	18.750	
4	2	12.500	12.500	31.250	
5	11	68.750	68.750	100.000	
Missing	0	0.000			
Total	16	100.000			

Frequencies for Design and Testing					
Design and Testing	Frequency	Percent	Valid Percent	Cumulative Percent	
3	7	43.750	43.750	43.750	
4	9	56.250	56.250	100.000	
Missing	0	0.000			
Total	16	100.000			

Frequencies for Results					
Results	Frequency	Percent	Valid Percent	Cumulative Percent	
1	1	6.250	6.250	6.250	
2	2	12.500	12.500	18.750	
3	7	43.750	43.750	62.500	
4	3	18.750	18.750	81.250	
5	3	18.750	18.750	100.000	
Missing	0	0.000			
Total	16	100.000			

Frequencies for Product & Conclusions ▼					
Product & Conclusions	Frequency	Percent	Valid Percent	Cumulative Percent	
1	3	18.750	18.750	18.750	
2	1	6.250	6.250	25.000	
3	2	12.500	12.500	37.500	
4	4	25.000	25.000	62.500	
5	6	37.500	37.500	100.000	
Missing	0	0.000			
Total	16	100.000			



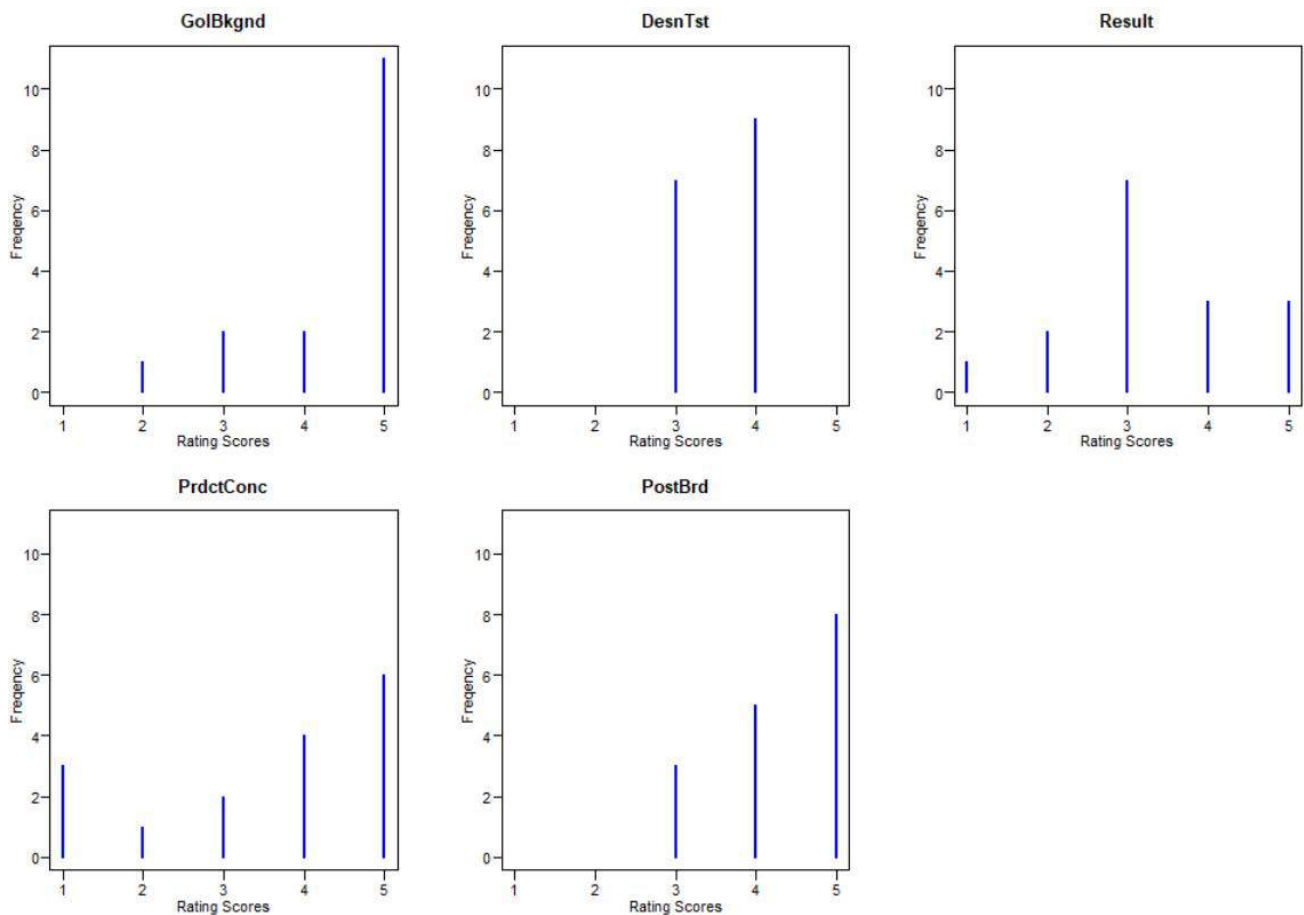


Figure 1. Performance of all groups on each individual measure

#### 4.2. How did the pre-service students view this type of activity?

The overall feelings about the project were positive, and the students listed several benefits of the assignment. One participant noted that it helped her to see that there really were plenty of opportunities to co-plan with other content areas:

“I think sometimes it can seem like a task to co-plan with teachers or peers of other content areas but when it really gets down to it, there are so many ways that make it possible for the subjects to co-exist and feed of each other.”

Other benefits the students listed included learning how to engage students and developing a better understanding of how to incorporate both math and science into one activity.

Although all but one said they found value in this type of activity, the question “*Do you believe you will be able to use ‘making’ in your classroom?*” revealed that participants still had misconceptions about design thinking problems and that there were several perceived barriers to conducting such projects in the school. For example, one participant commented that she would have to wait until the end of the school year because they would be “*done with the core curriculum that will be tested in the final exam. I think it will be difficult to incorporate in the actually [sic] school year because it will take time away from the core curriculum*”. Other major perceived barriers were cost and available technology, the culture of the school, and student misbehaviour.

The participants’ responses indicated many reasons these types of projects provided value to the teacher: *Design thinking created opportunities for authentic assessment; design thinking created culturally responsive classrooms; design thinking had an influence on teacher mindset; creating an engaging classroom experience; and teaching the students skills needed for the real world.* Participants saw that design problem thinking activities created opportunities for students to apply their knowledge, allowing the teachers to design an assessment that could authentically gauge student understanding of both math and science concepts.

Additionally, it gave students an opportunity. Design problem thinking also provides time for students to be *interactive*; they are *working with their hands* and *talking with each other*, something the participants viewed as being important to students at middle school level.

#### 4.2.1. Problems encountered

This question prompted responses that give many insights into the participants' experience working with the integrated STEM assignment. The responses were coded and then sorted into four main parent codes; *curriculum standards, team issues, design and implementation problems, and instructional problems*.

Teams had a lot of trouble attempting to incorporate curriculum standards from both subject areas within the same grade level. Some felt they had to sacrifice one standard or component to make it fit into the project. According to the post-questionnaire, students struggled most with incorporating math into their projects in more than just a superficial way.

Participants listed common team issues, such as time management, dividing up the work fairly, deciding who was in charge, and making sure everyone did their part, as major problems impacting their experience with the project. Many of the participants focused on design implementation issues instead of team or curriculum problems. The participants that listed design problems also shared how they were able to overcome the problems. Their responses show their ability to think through problems and generate solutions when faced with design issues. 34 responses on the questionnaire in regards to difficulties referred to prototyping difficulty, design issues, or building issues, or a combination of the three.

Responses that fell under the "instructional problems" code was quite interesting because it reflects on the participants lack of experience working with this type of project in their previous coursework. Those that listed instruction or introduction to the project as their main issue felt unclear about the purpose or over-all goal of the project. One participant even admitted that "*the small amount of detailed instructions given created anxiety and stress amongst my partners and I*", and another student lamented, "*It was intimidating and frightening to say the least*". Others felt there was a "*lack of structure*". One student described the project not as difficult, just different.

### 4.3 How would this activity impact the students' self-efficacy, interest or belief in the utility of teaching engineering, math, and science?

On both the pre and post questionnaire, students were asked to rate how comfortable they felt using 'making', design thinking, and the engineering design process in their future classroom using a scale from 1 to 7, with a score of 1 being extremely comfortable, a score of 4 meaning neither comfortable nor uncomfortable, and a 7 for extremely uncomfortable.

An independent-samples t-test was conducted to compare pre and post data conditions for each of the quantitative variables. All of the variables except for five were found to have no significant difference. Four out of the five variables violated the assumptions of homogeneity of variances. In those cases, equality of variance not assumed was used in the analysis. The variable questions that had significant results are reported in Table 3 below.

Results from the independent samples t-test indicated that there was a significant difference ( $t[51]=7.02, p=.01$ ) in the scores for the Design Thinking Comfortableness pre-condition ( $M=4.63, SD=1.65$ ) and the post-condition ( $M=2.22, SD=.79$ ). The analysis also revealed a significant difference ( $t[46]=4.19, p=.01$ ) in the Making Comfortableness variable for the pre ( $M=3.87, SD=1.87$ ) and post ( $M=2.17, SD=1.02$ ), as well as a significant difference ( $t[51]=4.46, p=.01$ ) in the Engineering Design Comfortableness pre ( $M=4.50, SD=1.61$ ) and post ( $M=2.70, SD=1.22$ ) conditions.

Two other variables related to math also produced significant results. The Usefulness of Math Studies variable ( $t[32]=2.14, p=.03$ ) showed significant differences in pre ( $M=4.63, SD=.61$ ) and post ( $M=4.13, SD=1.10$ ) conditions, as well as the Math Interest ( $t[40]=-2.31, p=.02$ ) pre ( $M=1.80, SD=1.12$ ) and post ( $M=1.80, SD=1.46$ ) conditions.

Table 3. Independent Samples Test

Question	Mean	SD	t	df	P value		
<b>How comfortable do you feel using Design Thinking in your future classroom? *</b>	Pre	4.63	Pre	1.65	7.02	43	.0001
	Post	2.22	Post	.795			
<b>How comfortable do you feel using 'Making' in your future classroom? *</b>	Pre	3.87	Pre	1.87	4.19	46	.0001
	Post	2.17	Post	1.03			
<b>How comfortable do you feel using the Engineering Design Process in your future classroom?</b>	Pre	4.50	Pre	1.61	4.46	51	.0001
	Post	2.70	Post	1.22			
<b>I am not interested in Math. *</b>	Pre	1.80	Pre	1.13	2.31	40	.026
	Post	2.65	Post	1.47			
<b>I think what we are studying in Math is useful for me to know. *</b>	Pre	4.63	Pre	.61	1.97	51	.05
	Post	2.65	Post	1.47			

\*Violated the assumption of homogeneity of variances

## 5. DISCUSSION AND CONCLUSION

Participants shared that very few had previously had an opportunity to participate in a design activity where creativity and inquiry were encouraged to foster thinking across content areas (Hernandez et al., 2013). This was reflected in the quantitative data that showed that students felt more comfortable using design thinking, ‘making’ and the engineering design process in their future classroom. Consequently, many struggled with how to combine multiple subject areas, and some felt like one subject had to be made secondary in order develop a grade-level appropriate design problem activity for the classroom. For a majority of these students, this was very much the first time also that the students had been introduced to crosscutting engineering content and methods, and this made many of them uncomfortable. This could possibly be the reason why the quantitative data showed that their interest in math went down ( $t[40]=2.31$ ,  $p=.02$  in the scores for Math Interest pre-condition ( $M=1.80$ ,  $SD=1.13$ ) and post-condition ( $M=2.65$ ,  $SD=1.47$ ), since they often felt math was pushed to the side. Additionally, the Usefulness of Math Studies variable ( $t[32]=2.14$ ,  $p=.03$ ) indicate that the students’ interest in math feelings about the usefulness of what they were learning about math actually declined after the intervention.

Additionally, questionnaire results showed that many students felt anxiety, confusion, and even anger about project directions given by the instructors that the students felt were too vague, meaning the directions left a lot of open doors as to what possibly the students could come up with. Similar to what Bruer (1993) discusses, the participants had gotten used to projects that impart facts and rote skills, aided by rubrics and directions that tell the participants exactly what was needed to receive an A on the project. This project, however, required the participants to employ higher-order thinking skills, and to transition from a classroom where students “perform assigned tasks under management of teachers into communities of learning and interpretation, where students are given significant opportunity to take charge of their own learning” (Brown, 1992, p. 141).

The value the participants placed on using ‘making’ and design problem thinking in the classroom reflect the four elements of learning common across good instruction (de Miranda, 2004), suggesting that engineering

indeed is a pedagogical strategy that promotes learning across disciplines (Roozenburg & Cross, 1991). Engineering methods used in the classroom, according to the participants, would allow students to engage with not just the product of learning but also the process, and through the design process learn to reflect and use existing structures of knowledge to guide and further their learning. Moreover, students learn how to interact as communities, allowing them to engage and interact with each other and the real world to openly share knowledge to further understanding. In addition, the participants saw that these types of activities provide students with an opportunity to learn how to apply knowledge that is learned in a way that moves beyond classroom or school boundaries (Brown, 1992).

Although all but one poster scored at least 60% on the final design poster, descriptive statistics reveal that the students struggled most with presenting the results and communicating how their conclusions were supported by design testing techniques. The rubric used for scoring required that students use and present a substantial amount of high quality data in a clear, thorough and logical manner to address the goal of the project. While many groups may have used data to come to their conclusions, these were not reported on their final solution poster. For others, the data was present on the poster, but not in a way that was logical or clear to the viewer.

The results also show that much like high school students who engage in projects that vertically and horizontally integrate applications from multiple STEM areas, engaging preservice teachers in these activities has the potential to improve appreciation of the integrated nature of STEM disciplines and the use engineering methods in the K-12 classroom (Hernandez et al., 2003). Students felt significantly more comfortable using 'Making', design thinking, and the engineering design process after developing an inquiry project which incorporated engineering design within the integrated methods course. In addition, qualitative questionnaire responses show the possibility of design problem thinking activities to increase participants' belief that they can adequately incorporate similar activities in their own classrooms (Lent, Brown & Hackett, 1994).

As the interest in Math and the usefulness of the Math being learned in the class declined after the condition in this study, future studies should also attend to how we can instruct teachers to successfully integrate cross-cutting standards, meaning multiple subjects can be included without one subject area feeling as if they are pushed to the side or made to be a simple materialistic addition to the assignment. In addition, more in depth interviews with the participants about the design process might also reveal team characteristics or dynamics that either contributed to successful teamwork or hindered group cohesion leading to one content area to feel pushed aside or less valued.

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## 7. APPENDICES

### 7.1 Appendix A: Engineering Design Project Judging Rubric for Poster Presentation

"adapted from the rubric developed by the American Society for Microbiology and the Committee for the Annual Biomedical Research Conference for Minority Students (ABRCMS)."

Score	Goals and Background	Design & Testing	Results	Product and Conclusions	Poster Board
5	<ul style="list-style-type: none"> <li>Background information was relevant and summarized well. Connections to previous literature and broader issues were clear.</li> <li>Project had a goal that was stated clearly and concisely; showed clear relevance.</li> </ul>	<ul style="list-style-type: none"> <li>Excellent choice of methods to address goal of design project.</li> <li>Excellent original thinking or innovation of technique.</li> <li>Excellent use of verification techniques use to inform design decisions</li> </ul>	<ul style="list-style-type: none"> <li>Substantial amounts of high quality data were presented sufficient to address goal of project.</li> <li>Presentation of data was clear, thorough and logical.</li> <li>Potential problems and alternative approaches presented.</li> </ul>	<ul style="list-style-type: none"> <li>Reasonable product/design conclusions were given and strongly supported with design testing techniques.</li> <li>A clear conclusion was connected to project goals and lessons learned were discussed</li> </ul>	<ul style="list-style-type: none"> <li>All expected components are present, clearly laid out, and easy to follow in the absence of the presenter.</li> <li>Text is concise, free of spelling or typographical errors; background is unobtrusive.</li> <li>Figures and tables are appropriate and labeled correctly.</li> <li>Photographs/tables/graphs improve understanding and enhance visual appeal.</li> </ul>
4	<ul style="list-style-type: none"> <li>A logical goal was presented.</li> <li>Background information was relevant, but connections were not clear.</li> <li>Goal of project was stated clearly, showed relevance beyond project.</li> </ul>	<ul style="list-style-type: none"> <li>Very good choice of methods to address the goal of the design project.</li> <li>Very good original thinking.</li> <li>Good use of verification techniques use to inform design decisions</li> </ul>	<ul style="list-style-type: none"> <li>Substantial amounts of good data were presented sufficient to address the goal of project.</li> <li>Presentation of data was clear and logical.</li> </ul>	<ul style="list-style-type: none"> <li>Reasonable product/design conclusions were given and supported with design testing techniques</li> <li>Conclusion was connected to project goals and lessons learned were discussed</li> </ul>	<ul style="list-style-type: none"> <li>All components are present, but layout is crowded or confusing to follow in absence of presenter.</li> <li>Text is relatively clear, mostly free of spelling and typographical errors; background is unobtrusive.</li> <li>Most figures and tables are appropriate and labeled correctly.</li> <li>Photographs/tables/graphs improve understanding.</li> </ul>

3	<ul style="list-style-type: none"> <li>• A project goal was adequately presented.</li> <li>• Background information was relevant, but connections were not made.</li> </ul>	<ul style="list-style-type: none"> <li>• Good choice of methods to address design project goal.</li> <li>• Good original thinking.</li> <li>• Adequate use of verification techniques use to inform design decisions.</li> </ul>	<ul style="list-style-type: none"> <li>• Adequate amounts of reasonably good data were presented to address design project goals.</li> <li>• Presentation of data was not entirely clear.</li> </ul>	<ul style="list-style-type: none"> <li>• Reasonable product/design conclusions were given.</li> <li>• Conclusions were not compared project goal and lessons learned were adequately discussed</li> </ul>	<ul style="list-style-type: none"> <li>• Most expected components are present, but layout is confusing to follow in the absence of the presenter.</li> <li>• Text is relatively clear, but some spelling and typographical errors; background may be distracting.</li> </ul>
2	<ul style="list-style-type: none"> <li>• The goal of the project was not clear.</li> <li>• A questionable hypothesis was presented and was not well supported or the goal of the project was not clear.</li> </ul>	<ul style="list-style-type: none"> <li>• Method not appropriate to address goal of the design project.</li> <li>• No original thinking.</li> <li>• Use of verification techniques use to inform design decisions was very limited of missing</li> </ul>	<ul style="list-style-type: none"> <li>• Some data were lacking, not fully sufficient to address design project goals.</li> <li>• Presentation of data was included, but unclear or difficult to comprehend.</li> </ul>	<ul style="list-style-type: none"> <li>• Conclusions were given.</li> <li>• Little connection to goal was apparent.</li> </ul>	<ul style="list-style-type: none"> <li>• Figures and tables not always related to text, or are not appropriate, or poorly labeled.</li> <li>• Photographs/tables/graphs limited and do not improve understanding.</li> <li>• Some expected components are present, but layout is untidy and confusing to follow in the absence of the presenter.</li> <li>• Text is hard to read due to font size or color, some spelling and typographical errors; background may be distracting.</li> <li>• Figures and tables not related to text, or are not appropriate, or poorly labeled.</li> <li>• Photographs/tables/graphs limited and do not improve understanding.</li> </ul>
1	<ul style="list-style-type: none"> <li>• The goal was inappropriate or not stated.</li> <li>• Little or no background information was included or connected.</li> </ul>	<ul style="list-style-type: none"> <li>• Methods section missing.</li> <li>• No original thinking.</li> <li>• A lack of verification techniques use to inform design decisions</li> </ul>	<ul style="list-style-type: none"> <li>• Presentation of data was missing.</li> </ul>	<ul style="list-style-type: none"> <li>• Conclusions were missing.</li> <li>• There was no connection with project goal.</li> </ul>	<ul style="list-style-type: none"> <li>• Some of the expected components are present, but poorly laid out and confusing to follow in the absence of the presenter.</li> <li>• Text hard to read, messy and contains multiple spelling and typographical errors; very poor background.</li> <li>• Figures and tables poorly done.</li> <li>• Visual aids not used.</li> </ul>

## 7.2 Appendix B: Pre-Questionnaire

1. What is your gender?
2. What is your content area?
3. What grade and subject would you like to teach in the future?
4. Describe any experience you have co-planning with other STEM content areas.
5. Describe what you know about design thinking.
6. Describe what you know about Maker-spaces, 'Making', or 'Making' in the classroom.
7. Describe what you know about the engineering design process.

For questions 8-10, the following scale was used:

1. Extremely comfortable
2. Moderately comfortable
3. Slightly comfortable
4. Neither comfortable nor uncomfortable

5. *Slightly uncomfortable*
6. *Moderately uncomfortable*
7. *Extremely uncomfortable*
8. How comfortable do you feel using Design Thinking in your future classroom?
9. How comfortable do you feel using ‘Making’ in your future classroom?
10. How comfortable do you feel using the Engineering Design Process in your future classroom?

For the last part of the questionnaire, they students were asked to rate whether they agreed or disagreed with the following statements, using the rating scale below:

1. Really Disagree
2. Somewhat disagree
3. Neutral
4. Somewhat agree
5. Really agree

<b>Item</b>	<b>Statement</b>
1	<i>I am not interested in science. (Reversed)</i>
2	<i>I think what we are studying in Engineering is useful for me to know.</i>
3	<i>I am interested in learning more about how to teach math</i>
4	<i>I think what we are studying in Math is useful for me to know.</i>
5	<i>When I have my own classroom, I am interested in teaching something related to engineering.</i>
6	<i>I think math is an interesting subject.</i>
7	<i>What I am learning in this class about teaching Math is relevant to my life.</i>
8	<i>What I am learning in this class about teaching Engineering is relevant to my life.</i>
9	<i>I think what we are studying in Science is useful for me to know.</i>
10	<i>I am not interested in engineering. (Reversed)</i>
11	<i>I think engineering is an interesting subject.</i>
12	<i>I think science is an interesting subject.</i>
13	<i>I think I will like learning about how to teach Science in this course.</i>
14	<i>I am interested in learning more about how to teach engineering</i>
15	<i>I find the content of this course in regards to teaching Engineering to be personally meaningful.</i>
16	<i>I am not interested in math. (Reversed)</i>
17	<i>I think learning how to teach math will be interesting.</i>
18	<i>I find the content of this course in regards to teaching Science to be personally meaningful.</i>
19	<i>I think I will like learning about how to teach Engineering in this course.</i>
20	<i>When I have my own classroom, I am interested in majoring in something related to science.</i>
21	<i>I find the content of this course in regards to teaching Math to be personally meaningful.</i>
22	<i>I've always wanted to learn more about teaching science.</i>
23	<i>I've always wanted to learn more about how to teach math.</i>
24	<i>I've always wanted to learn more about teaching engineering.</i>
25	<i>What I am learning in this class about teaching Science is relevant to my life.</i>
26	<i>I am interested in learning more about how to teach science</i>
27	<i>When I have my own classroom I am interested in teaching mathematics</i>

### 7.3 Appendix C: Post-Questionnaire

1. What is your gender?
2. What is your content area?
3. What grade and subject would you like to teach in the future?
4. Describe your experience in the design-inquiry project.
5. What problems did you encounter during this project? How did you solve these problems?
6. What portions of the project did you find difficult, and why?
7. Do you feel each content area was valued in your project? Why or why not?
8. Do you feel this experience provided you with an opportunity to focus on improving student-learning outcomes? Why or why not?
9. Do you believe you will be able to use ‘making in your classroom? Why or why not?

10. Do you believe you will be able to use design thinking and the engineering design process in your future classroom? Why or why not?
11. What value, if any, do you see in using design thinking in the classroom?
12. What value, if any, do you see in using 'Making' in the classroom?

*For questions 13-15, the following scale was used:*

- 1 *Extremely comfortable*
- 2 *Moderately comfortable*
- 3 *Slightly comfortable*
- 4 *Neither comfortable nor uncomfortable*
- 5 *Slightly uncomfortable*
- 6 *Moderately uncomfortable*
- 7 *Extremely uncomfortable*

13. How comfortable do you feel using Design Thinking in your future classroom?
14. How comfortable do you feel using 'Making' in your future classroom?
15. How comfortable do you feel using the Engineering Design Process in your future classroom?

For the last part of the questionnaire, they students were asked to rate whether they agreed or disagreed with the following statements, using the rating scale below:

1. Really Disagree
2. Somewhat disagree
3. Neutral
4. Somewhat agree
5. Really agree

<b>Item</b>	<b>Statement</b>
1	<i>I am not interested in science. (Reversed)</i>
2	<i>I think what we are studying in Engineering is useful for me to know.</i>
3	<i>I am interested in learning more about how to teach math</i>
4	<i>I think what we are studying in Math is useful for me to know.</i>
5	<i>When I have my own classroom, I am interested in teaching something related to engineering.</i>
6	<i>I think math is an interesting subject.</i>
7	<i>What I am learning in this class about teaching Math is relevant to my life.</i>
8	<i>What I am learning in this class about teaching Engineering is relevant to my life.</i>
9	<i>I think what we are studying in Science is useful for me to know.</i>
10	<i>I am not interested in engineering. (Reversed)</i>
11	<i>I think engineering is an interesting subject.</i>
12	<i>I think science is an interesting subject.</i>
13	<i>I think I will like learning about how to teach Science in this course.</i>
14	<i>I am interested in learning more about how to teach engineering</i>
15	<i>I find the content of this course in regards to teaching Engineering to be personally meaningful.</i>
16	<i>I am not interested in math. (Reversed)</i>
17	<i>I think learning how to teach math will be interesting.</i>
18	<i>I find the content of this course in regards to teaching Science to be personally meaningful.</i>
19	<i>I think I will like learning about how to teach Engineering in this course.</i>
20	<i>When I have my own classroom, I am interested in majoring in something related to science.</i>
21	<i>I find the content of this course in regards to teaching Math to be personally meaningful.</i>
22	<i>I've always wanted to learn more about teaching science.</i>
23	<i>I've always wanted to learn more about how to teach math.</i>
24	<i>I've always wanted to learn more about teaching engineering.</i>
25	<i>What I am learning in this class about teaching Science is relevant to my life.</i>
26	<i>I am interested in learning more about how to teach science</i>
27	<i>When I have my own classroom I am interested in teaching mathematics</i>



# Innovating a Professional Technology Teaching Programme Based on Student Teachers' Expectations and Experience of Work-integrated Learning

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The post graduate certificate in education (PGCE) is a one-year professional programme at South African universities that aims to train student teachers who have degrees or diplomas in technical or engineering fields as technology teachers in middle school (Grade 7-9) and/or high school (Grade 10-12). During the course of the year student teachers do two work-integrated learning (WIL) sessions (one per semester) in schools. The WIL session in the first semester takes place over three weeks during which student teachers are expected to mainly observe a mentor teacher's classroom practice. The WIL session in the second semester takes place over seven weeks during which student teachers are expected to teach most of the lessons. However, equipping student teachers who have qualifications largely unrelated to teaching with the relevant pedagogical content knowledge (PCK) that would enable them to become technology teachers in one year proves to be a challenge. The purpose of this paper is to determine to what extent the PGCE programme equips and develops technology student teachers with the necessary PCK. The research question used for this paper is: To what extent do the PCK related modules of the PGCE programme equip and develop technology student teachers with the necessary PCK? This qualitative study was conducted among the 2017 cohort of PGCE technology student teachers at a South-African Higher Education Institution. Data were gathered through open-ended questionnaires used to collate their expectations of the programme before it commenced. A document analysis was also done of their reflections of the WIL sessions. The findings highlighted a number of specific challenges faced by these student teachers during their WIL sessions and suggested possible innovations to the PCK-related modules of the PGCE programme to better equip them to face similar challenges later in their teaching careers.

*Key Words: Work-integrated learning, Pedagogical content knowledge, Technology teaching programme.*

## 1. INTRODUCTION

The PGCE qualification is designed to equip students with degrees with a professional teaching qualification. According to the university yearbook, the purpose of the Postgraduate Certificate in Education in Senior Phase (Grade 7 to 9) and Further Education and Training Teaching (Grade 10 to 12) is to deliver professionally qualified beginner teachers for the Senior Phase and Further Education Training of schooling. They are equipped with specialised teaching competence in at least one school subject in the Senior Phase and one school subject in the FET phase of schooling, a nuanced understanding of the integrated nature of theory and practice in education and the context of the teaching profession in South Africa.

In order to gain access to this Postgraduate Certificate in Education an applicant must have a first degree with two school related subjects, one on third year level and one on first year level. Or An approved National Diploma from an accredited higher institution with two school related subjects, one on second year level and one on third year level. Assessment of prior learning could also lead to entry or an advanced credit standing. Students should have sufficient study of the disciplines underpinning the specific teaching specialisations (subjects) to teach that particular school subject in a specific phase.

The qualification consists of three year modules, namely Education and Teaching Studies, Teaching Methodology and Practicum A in Senior Phase and Teaching Methodology and Practicum B in FET Phase Teaching. The purpose of the Education and Teaching Studies module is to assist students in developing a

sound understanding of adolescent development, learning and teaching, inclusive education and the statutory context of the teaching profession in South Africa to enable them to function as competent beginning teachers and to teach in a critically-reflective manner. The Teaching Methodology and Practicum modules focus on developing students' Pedagogical Content Knowledge, and are the focus of this paper.

Students may register to complete the qualification either full-time (1 year) or part-time (2 years). • Students who are employed on a full-time basis may only register for the part-time programme. Prescribed periods of school based practicum/ work integrated learning (WIL) must be completed in approved schools during the time of study. Students complete their school based practicum/ WIL during the year in which they study their methodology modules. These school based practicum/ WIL sessions are planned as follows: Three consecutive weeks during the first semester, and seven consecutive weeks during the second semester.

PGCE student with Technology as specialisation, typically take the Teaching Methodology and Practicum module focussing on Senior phase Technology, as well as one of the FET Teaching Methodology and Practicum modules, namely: Civil Technology, Electrical Technology, Engineering Graphics and Design or Mechanical Technology. The purpose of these modules is to assist students in developing pedagogic content knowledge in their field of specialisation to enable them to function as competent beginning learning programme designers and learning mediators and to teach in a critically-reflective manner.

Main focus of the teaching methodology module in each subject or subject area is developing students' pedagogic content knowledge. Themes that will be addressed in all teaching methodologies, but specified for the subject area: Pedagogical content knowledge (PCK) development, focusing on Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PaP-eRs) (Loughran, J.; Mulhall, P. & Berry, A: 2004).. Classroom communication Design and delivery of teaching plans and lessons Teaching methods The school curriculum Assessment for and of learning Classroom management.

## **2. LITERATURE REVIEW**

As mentioned earlier, the focus of the teaching methodology modules in the PGCE qualification is the development the student's pedagogic content knowledge. Shulman (1986) describes pedagogical content knowledge as including the most useful forms of representation of the most regularly taught topics in one's subject area, as well as the most powerful analogies, illustrations, examples, explanations, and demonstrations, i.e. the ways of representing and formulating the subject that make it comprehensible to others. He argues that since there are no single most powerful forms of representation, the teacher must have a wide variety of alternative forms of representation at his/her disposal, developed over time through research and experience. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult. This implies an understanding of the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.

Loughran, J.; Mulhall, P. & Berry, A (2004) identified two tools to uncover, document, and portray science teachers' PCK to help identify and capture PCK and appropriately represent it to others. These are: Content Representation (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs). CoRe sets out and discusses science teachers' understanding of particular aspects of PCK (e.g., an overview of the main ideas; knowledge of alternative conceptions; insightful ways of testing for understanding; known points of confusion; effective sequencing; and important approaches to the framing of ideas) PaP-eRs are developed from detailed descriptions offered by individual teachers, and/or as a result of discussions about situations/ideas/issues pertaining to the CoRe, as well as classroom observations. A PaP-eR therefore develops through the interaction of the prompts, questions, issues, and difficulties that influence the particular approach to teaching that content to which the PaP-eR is tied and reflects the richness of the teacher's understanding of science teaching and learning in that field.

a model proposed by Banks, Barlex, Jarvinen, O'Sullivan, Owen-Jackson and Rutland (2004:142-146) for conceptualising teacher professional knowledge, present a graphic framework (Figure 1) that helps to visualise the different aspects of technology teacher knowledge. School knowledge could be seen as being intermediary between subject knowledge (knowledge of technology as practiced by different types of technologists for

example) and pedagogical knowledge as used by teachers (powerful analogies, illustrations, examples, explanations and demonstrations). This would however negate the dynamic relationship between the categories of knowledge implied by the diagram. Teachers' subject knowledge is enhanced by their own pedagogy in practice and by their contextual expectations which form part of their school knowledge. Thus a teacher often understands a topic better after teaching it to learners.

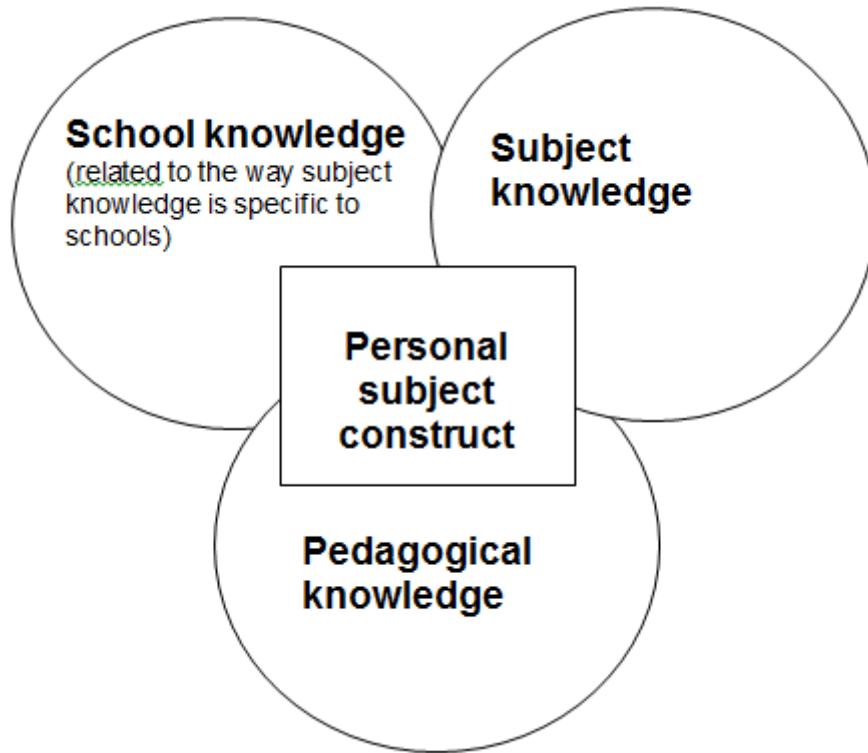


Figure 1: A model for conceptualising teacher professional knowledge (Banks et al., 2004:143).

Personal subject construct is a combination of elements of school knowledge, subject knowledge and pedagogic knowledge which blend with other influences to provide a view of the purpose, value, content and methods of technology as a school subject. The dynamic intersection of subject knowledge, school knowledge and pedagogical knowledge is what constitutes teacher professional knowledge. At the centre of this process are the teacher's personal constructs, an intricate collection of experiences of learning, a personal view of what "good teaching" entails and the teacher's own belief of what the purposes of the subject are. All these aspects together underpin a teacher's professional knowledge. Banks et al. (2004) and Jones and Moreland (2004) are of the opinion that when a teacher has to teach technology for the first time, significant changes need to take place in the teacher's "professional knowledges". Jones and Moreland (2004) distinguish between three dimensions of knowledge namely, knowledge about technology, knowledge in technology and knowledge about teaching technology.

### 3. METHODOLOGY

The purpose of this paper is to determine to what extent the PGCE programme equips and develops technology student teachers with the necessary PCK. The research question used for this paper is: To what extent do the PCK related modules of the PGCE programme equip and develop technology student teachers with the necessary PCK? This qualitative study was conducted among the entire 2017 cohort of PGCE technology student teachers at a South-African Higher Education Institution. Data were gathered through open-ended questionnaires used to collate their expectations of the programme before it commenced. A document analysis was also done of their reflections of the WIL sessions.

An open ended questionnaire was used at the first meeting to determine students' expectations of the module/qualification. The question used for this purpose was: "Write a few sentences on your expectations of

the PGCE”. Students had to submit reflections on their experiences during the WIL sessions. The format of this reflection was not very prescriptive, so students were free to express their experiences as they saw fit. The initial questionnaires as well as the reflections on the WIL were analysed and through open coding, themes and sub-themes were identified (Merriam, 1998; Creswell, 2005). The sample included all the students of the 2017 PGCE cohort (12 students).

## **4. FINDINGS**

### ***4.1. Students’ expectations of the PGCE***

In order to determine what the students’ expectations of an analysis of the open question “Write a few sentences on your expectations of the PGCE” yielded the following findings:

#### ***4.1.1. Students had the following academic expectations:***

##### **Students expected to complete the PGCE successfully**

“passing with flying colours”

##### **Students expected to have fun**

“Expect more fun”

#### ***4.1.2. Students had the following professional expectations:***

##### **Students expected to be equipped with PCK**

“Equipped with skill, methodologies”, “Learn and gain knowledge on teaching methodologies”, “widen my skills, develop teaching and tutoring skills”, “gain valuable practice in teaching”, “Equipped with knowledge so that I can apply the knowledge that I already have”, “Gain knowledge on the most effective methods of how teaching and learning can be made easier – achieving greater results”, “Gain knowledge and skills on how to educate scholars, to gain the know-how on how to apply my skills to help students to learn.”, “Acquiring methods on how to educate learners”

##### **Students expected to develop the ability to manage a classroom**

“Acquiring methods on how to handle learners”

##### **Students expected to develop into someone who helps others**

“in a position of enriching others”, “expect to change young people”, “Make our country proud by teaching children”, “love of changing people’s lives – demand of skilled teachers in our country”

### ***4.2. Students’ reflections on their experiences during the WIL sessions***

A document analysis of the students’ reflections on their experiences during the WIL sessions yielded the following findings:

#### ***4.2.1. What students found challenging during their WIL experience***

##### **Classroom management and discipline is a challenge**

“Big challenge to maintain discipline – difficult if not impossible to manage the class effectively”

“I have to implement some changes in the way I manage the class”, “to control the class was not easy.”

##### **Large numbers in classes is a challenge**

“It is a challenge to work with a class that has a large number of learners”, “Had to work with larger groups to accommodate all learners”, “The Grade 8 classes were very crowded- about 40 learners per class.”

## **The language ability of learners is a challenge**

“The educator can try explain to the learners in their mother tongue to accommodate learners whom don’t understand English.”, “The language barrier... I had to interpret in isiZulu”

## **Some mentor teachers were not good examples**

“most of the teachers seemed as they did not obey the school rules ... would arrive late at school”

“Teacher was off on sick leave and the responsibility was upon me to cover up the work”

“some teachers showed their bad attitude toward other teachers...”

## **Lack of resources at some schools were challenging**

“it was difficult for me in terms of school material”, “...equipment used for practical were too old and damaged.”,

### *4.2.2. What students found to be enabling during their WIL experience*

#### **Some mentor teachers were good examples**

“...Principle of respect from staff of the school to learners, vice versa.”, “The humanity that I have seen in that school was very amazing”, “The discipline that learners and teachers had in that school was amazing”. “I was impressed with the school staff effort as well as hard work they put in.”, “The staff is very welcoming and willing to grow student teachers in this profession.”, “The mentor was important to me because she was grooming me also.”

#### **Some schools are well managed**

“and I noted a couple of positive things about how (the) school is managed”

#### **Some schools have ample resources**

“School has resources... makes learners to be more interested in learning”

### *4.2.3. What students perceived to have gained through their WIL experience*

#### **Students made the connection between theory and practice during WIL**

“WIL was an eye opener for me because I was introduced to the practical world of the theory I have been taught.”

## **Students developed their PCK through the WIL experience**

“I was prepared in terms of subject knowledge. It was easy for me to use examples that are essential and understandable to the learners, ...combine information whereby I used more than one different textbook.”, “The mistake I made... in power point... I was reading for them rather than explanation. I noticed the lesson had not gone well before I received feedback from the mentor. Had to correct my first mistake by explaining more... writing in the board and interact with learners and limit focusing on slides. I could feel that my learners were with me the whole presentation by reading their facial expressions. I managed to cover the whole lesson in time...My mentor indicated I should work on voice projection and explaining and writing on the board at the same time. I reworked those areas and I saw the improvements.”, “The students could see that I was confident... students were engaged... The type of questions the student was asking was actually perceived before the lesson and I incorporated them on the lesson plan. When learners are participating in class they concentrate more... I came to class with a model... and they were really interested.”, “I noticed that it is impossible to teach someone something when you do not have the Pedagogical knowledge.”, “This course has taught me that it is imperative to have (a) lesson plan for each lesson... this will promote structure to the lesson and will encourage teaching.”, “I think the issue of clustering a lot of information on the screen can cause these misconceptions.”, “Some learners require more time to understand...”, “It is impossible to teach the same way to different learners because of their differences.”, “The type of examples in class need to be correlated to what learners are interested in and what they can relate to.”, “I learned that visual teaching is very important to learners because they won’t forget.”, “One of the things that really stood out for me was the variation in the tone of voice used by the teacher, with the firm and strict tone seemingly the more effective”, “The students were actively participating and responding to my questions and commands. I felt very comfortable.”, “Lessons do not always go as planned, learners may not have understood previous lessons that is a building block for the planned lesson.”, “Don’t always give answers to learners

when they ask you questions, but ask leading questions so that they can make sense of what they are asking”, “I learned some of the teaching skills from my mentor when I was observing her lessons.”

### **Students developed a realisation their responsibility**

“Teachers need to be role models...”, “As a teacher I need to make sure that everyone in my class is understanding what I am teaching... and make sure that I accommodate each and every learner.”

### **Students developed their classroom management skills**

“I managed to set up rules in my classroom... this helped students to take me serious.”, “All learners would wait for the teacher to check that the class is in order then they will be dismissed by the teacher. This kept order in class and it was easier to manage the class.”, “Time management is very important in a lesson”, “Classroom management has a great influence on how a lesson goes”, “Discipline is key in class”

### **Students had a positive experience of the WIL**

“I feel very motivated after I heard my mentor’s evaluation comments.”, “I really enjoyed working with the young ones”, “I was very happy to hear constructive criticism”

## **5. DISCUSSION AND CONCLUSION**

When students were asked to write a few sentences on their expectations of the PGCE, there were both academic and professional expectations identified.

Under Academic expectations, students expected to complete the PGCE successfully and to have fun in the process. The expectation to have fun was novel and not anticipated.

With regard to professional expectations for the PGCE students expected to be equipped with PCK. They also had the expectation of developing the ability to manage a classroom and to, by completing the PGCE, develop into someone who helps others.

Regarding students’ experience of WIL, three categories were identified, namely: What students found challenging during their WIL experience, What students found enabling during their WIL experience, and What students gained through their WIL experience.

With regard to what students found challenging during their WIL experience, students found it challenging to effectively manage and to maintain discipline in their Classrooms. The large numbers of learners in some of the classrooms exacerbated this problem. A further issue that the students found to be a challenge was the language ability of the learners. Learners would be enrolled in an English medium school, without being sufficiently proficient in English to learn through English as a medium. A further challenge was that students did not receive the necessary support from the teachers who were supposed to mentor them, in fact some of these teachers saw the student as a replacement for them and shifted all responsibility over to the student. This is indicative of a flaw in the WIL system and the relationship between the schools and the faculty. Another challenge that students struggled with was the lack of resources at some schools that made it difficult to teach effectively.

These challenges experienced and described by the students during WIL is unfortunately a reality in a large number of schools in the South African context where a lot of schools are dysfunctional to some degree. Students are advised to apply for WIL at schools that they know to be functional in order to ensure that they have the most productive WIL experience possible, but notwithstanding a number of them end up in schools with the challenges mentioned.

With regard to what students found enabling during their WIL experience, it was heartening to note that some mentor teachers actually took their role seriously and were good mentors and role models to our students. It

was also good news that some schools are well managed and have all the necessary resources to give the student teacher the best possible learning experience during WIL.

With regard to what students gained through their WIL experience, A very positive finding was that students felt that they made the connection between theory and practice during their WIL experience in schools. The data suggests that students' CoRes and PaP-eRs are developed through their time at schools during WIL, and that their personal subject constructs are thus developed. The assumption that students in the PGCE presumably gained ample discipline content knowledge through studying for their degree or diploma is sometimes not completely accurate. A student might, for example, have a diploma in heavy current electrical engineering, which would allow her to qualify for a PGCE in FET Electrical Technology. The FET Electrical technology school subject however includes content on digital systems which she does not have the subject knowledge for. This is a further challenge for some students who have to develop their subject knowledge together with their school knowledge and pedagogical knowledge.

It was evident that the students developed a realisation of their responsibility as teachers during the WIL experience, and that a number of them take this responsibility quite seriously. Students remarked that their ability to manage a classroom developed and improved over the time they spent doing WIL in schools. It was quite heartening to find that some of the students had a positive experience of the WIL, and although it was not quite articulated as such could be interpreted as "having fun" as mentioned in the expectations.

The PGCE students' exposure to the classroom situation during the ten weeks in one year is relatively short compared to undergraduate students who study for four years and are exposed to WIL in schools from one week in their first year, increasing to three weeks in their second, and third years, and then Ten weeks in their fourth year. This means that they have much less time than their undergraduate counterparts to develop their PCK in front of a class before they get their qualification. This is an inherent shortcoming of the PGCE model.

The findings highlighted a number of specific challenges faced by these student teachers during their WIL sessions and suggested possible innovations to the PCK-related modules of the PGCE programme to better equip them to face similar challenges later in their teaching careers. It became clear from the students' experience of WIL that the mentor teacher allocated to students often did not provide sufficient support regarding classroom practice and PCK. Whether this happened due to inability or unwillingness from the mentor teachers' side to help or because the students do not have the courage to ask for help is not clear. Possible innovations to better support students during their WIL could include a "PCK hotline" where students could quickly get into contact with an experienced teacher who is willing to help with issues experienced by the student in the classroom or when planning lessons. It would be useful to get feedback from these same students after they have been teaching for a year or two to get their perspective of the PGCE's value for them and their experience of the teaching profession.

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# Considerations for developing Integrated-STEM Courses at the Senior Secondary School Level in New Zealand

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This paper considers the concept of integrated-STEM education in the context of cross-curricular course design in secondary schools in New Zealand. It discusses what is meant by ‘integrated-STEM’ education where Technology is the key curriculum area and where Science and Mathematics knowledge contribute significantly to the development of more sophisticated technological outcomes than would otherwise be the case with ‘stand-alone’ Technology. It includes an overview of current senior school assessment in New Zealand (the National Certificate of Educational Achievement assessment standards), and its suitability for credentialing courses that cross curricula boundaries. The paper also considers managing an implementation process for integrated-STEM courses and the significance of the literature on the educational theory of “transfer of learning” relevant to an integrated-STEM type course. The paper finds significant limitations to cross-curricular course design at the senior secondary school level in New Zealand created by the present senior assessment structure of the National Certificate of Educational Achievement. Apart from STEM education courses that have been designed with a strong technology focus, scope for crossing traditional subject boundaries for assessment purposes is largely absent in the wording of the assessment standards available for grading student work.

*Key Words: Integrated-STEM, Course design, Assessment, Learning Transfer.*

## 1. INTRODUCTION

This paper discusses the concept of integrated-STEM education and comments on three related considerations that influence not just STEM education but cross-curricula course design in general. While the context of this discussion is the senior secondary level in New Zealand, the paper identifies considerations that are likely to be of interest to technology educators from other countries. The paper builds on previous work (Granshaw, 2016; Granshaw & Hall, 2017) that discussed the nature of STEM education and the scope that exists in New Zealand for teachers to develop integrative STEM courses at Years 11–13.

The discussion is presented under the following headings:

- The concept of integrated-STEM education
- Senior secondary curriculum and assessment in New Zealand
- Specification for a STEM course centred on technology<sup>1</sup>
- Important considerations for integrated-STEM education

The final section covers three considerations: The manageability of implementing integrated STEM education; the significance of the literature on transfer of learning; and the limitations to cross-curricula design in New Zealand created by structural features of the National Certificate of Education of Educational Achievement.

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<sup>1</sup> This paper uses upper case for the first letter in the spelling of Technology, Science, Mathematics, etc. when referring to the titles of the learning areas of the New Zealand Curriculum (2007). However, lower case is used for the first letter when referring generally to technology, mathematics, etc.



## 2. THE CONCEPT OF INTEGRATED-STEM EDUCATION

The acronym STEM (science, technology, engineering, mathematics) is used to group key learning areas that are considered important if a nation is to compete in a global economic and scientific world (Granshaw, 2016). As pointed out by Vasquez (2015), the concept of STEM was introduced in the 1990s by the National Science Foundation in the United States but gained impetus in the next decade when it appeared that American students were being left behind in their preparation for globalisation; other countries were considered to be “out-STEMming” (Vasquez, 2015, p. 11) the United States.

This paper embraces the notion of integrated-STEM education (Williams, 2011) where students draw together subject content knowledge from contributing STEM subjects in order to solve design problems with a technological focus. The case for an integrated-STEM design is that it enhances learning opportunities and more sophisticated outcomes by removing ... “the traditional barriers separating the four disciplines and integrates them into real-world, rigorous, relevant learning experiences for students” (Vasquez, 2015, p. 11). However, integrated-STEM education should not be seen as a new stand-alone curriculum area; each of the four disciplinary areas has pedagogical features and a distinctive content that gives it the status of a discipline in its own right. This includes technology, which should not be treated simply as a servant to the other learning areas (Williams, 2011). Indeed, Compton (2009) argues that it is better to talk of “curriculum collaboration” than “curriculum integration” because the concept of collaboration captures the importance of different curriculum areas maintaining their own identity. Notwithstanding the argument by Compton, we will continue to use the concept of “integrated-STEM education” because the focus is not on merging whole curriculum areas but on designing courses (or units of study) that are intended to build cross-curricula learning connections.

As noted by Vasquez (2015), integrated-STEM education is an approach to teaching and learning that can take various forms. It does not have to include all four disciplines at once, for example, it may involve students learning about chemical or physical phenomena while recording observations in numerical form for later mathematical analysis and prediction. Vasquez (2015), drawing upon earlier work (Vasquez, Sneider & Comer) , presents a model of increasing levels of integration to describe the various forms of integration that may be involved. Four levels are depicted: Disciplinary, Multidisciplinary, Interdisciplinary, and Transdisciplinary. These are distinguished as follows:

- **Disciplinary:** Students learn concepts and skills separately in each discipline.
- **Multidisciplinary:** Students learn concepts and skills separately in each discipline but in reference to a common theme.
- **Interdisciplinary:** Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills.
- **Transdisciplinary:** By undertaking real-world problems or projects, students apply knowledge and skills from two or more disciplines and help to shape the learning experience.
- (Vasquez, 2015, p. 13: Taken from Figure 1, “The Inclined Plane of STEM Integration”)

The focus of the present paper is predominantly on the last of the levels — transdisciplinary learning — as this level captures well the intent of the writers here in encouraging the design of courses that build cross-curricula learning connections. An important ingredient of transdisciplinary learning is captured by the final words, that students “help shape the learning experience”. This incorporates the idea that students are engaged purposively in making meaning from their cross-curricular explorations and testing their understanding within the context of real-world problems. As noted by Granshaw and Hall (2017):

An integrative STEM programme has the potential to provide opportunity for students to engage in more complex design solutions and scientific/technological processes than might be the case if their study was confined to Technology, Science or Mathematics alone. ... Consequently, the scope of a student’s scientific, technological or mathematical knowledge may be expanded and/or deepened as they undertake design projects that give meaning to concepts and processes in a way that is not exemplified in subject specific learning. (p. 5)

### 3. SENIOR SECONDARY CURRICULUM AND ASSESSMENT IN NEW ZEALAND

The two dominant national educational provisions related to curricula at the senior secondary level in New Zealand are the New Zealand Curriculum (NZC) (2007) and the National Certificate of Educational Achievement (NCEA). The latter was introduced in 2002 and represented a radical shift in senior school assessment from a norm-referenced to a standards-based system.

The NZC (2007) document is separated into a “front end” description and a more detailed statement of each of the eight learning areas that are available to students. The front end includes the vision of learning for students, the principles that the curriculum is intended to embrace, and the values and key competencies that should be integrated into all learning areas. The eight learning areas are identified as: English; The Arts; Health and Physical Education; Learning Languages; Mathematics and Statistics; Science; Social Sciences; and Technology. An important feature of NZC (2007) is that while traditional school subjects are embedded to a greater or lesser extent within particular learning areas, they are often identified in ways that are intended to give a more progressive and open-ended description than traditionally presented by subject syllabus prescriptions. For example, Science is structured under five strands: Nature of Science; Living World; Planet Earth and Beyond; Physical World; and Material world. However, the Living World focuses strongly on what is more traditionally called biology and the last two strands respectively give strong emphasis to physics and chemistry.

Each learning area of NZC (2007) is structured around eight levels, covering Years 1 to 10 (Levels 1-5) and Years 11 to 13 (Levels 6 to 8). The curriculum for each learning area is specified in terms of the “achievement objectives” that are deemed appropriate for each level. As mentioned, the description of each learning area is broad and open-ended (i.e. lacking syllabus detail) with the intention that schools should have the flexibility to select content and design courses that are suitable for their students and communities. While this flexibility has not been well received by all involved in education, the Ministry of Education has worked closely with subject associations and similar groups to provide documents and professional development that give more guidance and specificity to assist schools in their course developments.

The NCEA is the main qualification that students in the senior secondary school undertake in their final three years. Scholarship examinations are also provided and are intended to give students the opportunity to excel in their final year (some of the more able students may sit earlier in Year 12) so as to compete for financial support in relation to their subsequent tertiary studies. Some schools also offer Cambridge examinations or the International Baccalaureate Diploma (IBD) as an alternative to NCEA.

In relation to NCEA (the main vehicle for assessing students’ school achievement), each learning area is categorised into a number of assessment standards — these may vary in number but often exceed 10 for a particular sub-area or strand at a given year level — and schools design courses that embed a subset of these standards. Each standard has a credit weighting (these vary) and a course typically involves 5-6 standards totalling 18–24 credits. Up to three standards in a course are assessed by an external end-of-year examination; exceptions exist such as Visual Art, which is assessed through portfolio submission. Moderation exists for monitoring the grading of internally assessed standards across schools. The result for each student on each standard is graded at one of four levels: Not Achieved; Achieved; Merit; and Excellence. While there are no overall course results, students can obtain an endorsement within learning sub-areas (these sub-areas often align with traditional subject classifications) for achieving sufficient credits at Merit or Excellence level.

Unfortunately, the design of NCEA has been variously criticised by a number of writers. For example, Hall (2000, 2005, 2016) has criticised NCEA for providing a structure that “fragments” course design, teaching and learning. As noted by Hall (2016), the design of NCEA ... “fosters the breakdown of the curriculum into learning chunks (I have no problem with this), but does not foster anything like as well the knowledge and skills that students need for understanding how the chunks relate to each other” (p. 1). As noted by Granshaw (2016), the argument advanced by Hall has an important implication for integrated-STEM course design:

If a school designs a course which crosses traditional subject boundaries, teachers must draw upon existing standards if the assessment of student work is to receive credit for NCEA. Yet the very design of a cross-curriculum course will involve

learning that is about the important connections between the contributing subjects. Unfortunately, there are no standards for assessing these relationships unless an existing standard in a subject is fortuitously worded in a way that a teacher can adapt the standard to the course. (p. 7)

The issue raised by Hall is discussed more fully in the final section of this paper.

#### **4. SPECIFICATION FOR A STEM COURSE CENTRED ON TECHNOLOGY**

Appendix A sets out an example of a generic specification for an integrated-STEM course that is centred on technology as the principal subject, with mathematics and science being contributing subjects.

The aim is to give indicative information that should help readers form a clearer picture of the thinking that has guided the writers in preparing this paper. It should also help provoke systematic thought for readers who are thinking of developing an integrated-STEM course. The design is deliberately generic so that readers can position their own content and teaching within the framework provided. The focus is on the senior secondary school curriculum in New Zealand, with assessment of student work contributing to the NCEA.

As noted by Hall (2013), although course design can follow different routes and employ different models, certain elements are normally addressed. These include the course title, the purpose of the course, the learning objectives, and so on. Appendix A identifies eight elements that are commonly addressed in course design.

As noted in Appendix A, the purpose of the course would be to give students the opportunity to undertake a design and development project that would deepen their theoretical and practical knowledge of technology and gain a strong appreciation of the significance of cross-curriculum learning for problem solving and creative design. The course could be adapted to either students who intend to proceed to tertiary education or students who are following a vocational pathway in schools.

#### **5. IMPORTANT CONSIDERATIONS FOR INTEGRATED-STEM EDUCATION**

This concluding section covers three themes:

- Manageability of implementing integrated STEM education
- Significance of the literature on transfer of learning
- Limitations to cross-curricula design created by NCEA

##### ***5.1 Manageability of implementing integrated STEM education***

The notion of cross-curricula education is common in primary and intermediate schools in New Zealand, reflecting some of the intended “spirit” of NZC (2007). However, an integrated curriculum is far less common in secondary schools, particularly at the senior secondary level. One obvious factor is that primary and intermediate teachers are expected to be generalists, and teach most areas of the school curriculum. However, secondary teachers focus on one or two subject areas and are somewhat more specialised in the learning areas that they teach. In addition, the nature of the senior secondary school curriculum is such that students typically select four, five or six subjects to study for the NCEA. With increasing curriculum specialisation, students quickly become distanced from their earlier learning and significant knowledge gaps develop for many students within some of the subjects contributing to a cross-curricular course design. For example, a Year 13 integrated-STEM course of the kind described in Appendix A would be difficult for students to undertake if their contributing science or mathematics knowledge was left well behind at Year 11 level.

From a manageability perspective, it is clear that an integrated STEM course is likely to require cooperation between different subject specialists unless the principal teacher has the background to teach all of the contributing knowledge. There are, of course, many technology teachers who do have strong backgrounds in science and mathematics. However, a more likely scenario is that team-teaching will be needed for a cross-curricular course to be mounted. Currently at the senior school level in New Zealand, this is difficult to achieve because of time-tabling restrictions, teacher workload, and insecurity amongst some teachers in taking on an

unfamiliar approach to teaching and learning. If a cross-curricular approach is adopted, all contributing teachers need to buy into the purpose and rationale of the course and engage in its design and implementation. As noted by Granshaw and Hall (2017), “Co-operative teaching practices are also important for helping teachers who are new to cross-curricular design to develop a sense of self-efficacy for undertaking the design and teaching involved” (p. 5). In addition, teachers have an important role in ensuring that materials, tools, machinery, digital technology, and scientific facilities are available. Teachers may also need to liaise with external communities such as people in industry to help students gain access to real world contexts for their project designs. Teachers will also need to consider very carefully the way students with significant gaps in their knowledge can be brought up to speed. All in all, cross-curricular course design and implementation brings with it a range of manageability and professional learning needs for the participating teachers that go beyond what is normally required for single subject courses.

## ***5.2 Significance of the literature on transfer of learning***

In the preface to their text on transfer of learning, Leberman, McDonald, and Doyle (2006) make six claims for the importance of transfer, the first three of which are listed below:

- Transfer of learning is essentially the crux of all learning.
- The concept of transfer is cross-disciplinary and has applicability in many domains of life.
- Knowledge of transfer is essential for all learners and their educator or supervisors who want to improve and facilitate future learning.

(Leberman, et al., 2006, Preface)

In a similar vein, Doyle (manuscript in preparation) makes the point that, “Learning and transfer are inextricably linked. There can be no transfer without learning. Transfer is the manifestation of learning, and likely a prerequisite of new learning.” The last sentence identifies that the definition of transfer of learning has expanded to include, as noted by Leberman et al. (2006), the preparation of students for future learning. This involves the recognition that transfer is not simply about knowledge and skills, but also about attitude and motivation so that students actively seek out opportunities to apply earlier learning to later contexts.

The position of the above authors, which appears to be quite widely (but not unanimously) held by learning theorists, is that transfer is evidenced when past learning fosters new learning. However, the ease to which transfer takes place is related to a number of factors. These include, but are not limited to:

- The similarity of the new and old learning situations and contexts
- The existing knowledge and skills of the learner
- The particular abilities or talents that a person already possesses
- The experience and expertise of the learner
- The opportunities provided by a teacher for learners to explore ways of seeing connections, of integrating ideas, and using higher order thinking processes (e.g., different forms of reasoning and problem-solving)
- The encouragement given by teachers to learners to develop their metacognitive capacity (which includes the development of self-reflection).

An important distinction in the literature is that between “near” and “far” transfer. This is captured in the first of the preceding bullet points: Near transfer relates to learning that crosses between similar contexts or situations; far transfer involves the learner’s ability to see underlying principles of similarity in situations that are not obviously alike.

The above points cannot do justice to the extensive research and debate that exists on transfer of learning. However, there are at least two corollaries of the literature that require consideration for cross-curricular course design and teaching.

The first is that the teaching team needs to address individually and collectively the professional learning that will assist them to become effective in a cross-curricular context. This will involve, to a greater or lesser extent, teachers reading widely on STEM education, transfer of learning, and particular pedagogical approaches that

could be used to assist students become effective in their cross-curriculum learning (e.g., collaborative learning, problem-based learning, experiential learning, and action learning). Peer sharing of knowledge and pedagogical strategies is important, and externally available professional development and learning opportunities should also be sought out (e.g., tertiary level courses, Ministry of Education and subject association workshops, and attendance at professional conferences). The development of a community of practice on cross-curricular teaching and learning, with teachers engaging across schools, is a further strategy that could provide beneficial and exciting developments.

The second is that the goal of “curriculum integration” requires a close analysis of what is expected of learners, what pre-requisite knowledge and skills they should have, what specific prerequisite knowledge gaps need addressing for individual learners, and (as mentioned under the previous sub-heading) what resources or strategies should be put in place for helping such learners get up to speed so that they can move forward with the new learning. While the life-long learning target of independent learning might be a positive goal for students, such a development actually requires on the part of teachers careful planning and structuring of the learning environment.

### ***5.3 Limitations to cross-curricula design created by NCEA***

As noted earlier, the design of NCEA has been criticised by various writers for its “fragmentation” impact on course design, teaching and learning. Research recently undertaken and reported in Granshaw and Hall (2017) investigated the suitability of NCEA standards for assessing cross-curricula learning. The analysis focused on the wording of standards and an inspection of on-line resources that are mentioned in explanatory notes to specific standards. This was done for all three levels of Technology. It should be noted that in Technology there are 121 achievement standards over the three levels of NCEA; these are broken down into “technology generic” and “specialist categories” of technology knowledge and skills. The latter comprises standards related to Construction and Mechanical Technologies, Design and Visual Communications, Digital Technologies, and Processing Technologies. An inspection was also undertaken of standards in Mathematics at all three levels of NCEA, and the second and third levels of biology, chemistry, and physics within the Science learning area. For comparative purposes, an inspection was undertaken of the titles of achievement standards in four non-STEM Social Science subjects (geography, media studies, psychology, and economics) at the second and third levels.

The overwhelming conclusion reached by the writers in relation to the Social Science subjects chosen for inspection was that NCEA provides little or no explicit opportunities for assessing cross-curricula learning. Standards are largely written to match important content and skills (processes) that are subject-specific. In relation to Science and Mathematics standards, a similar conclusion was reached apart from one standard in chemistry at the third level of NCEA. This standard is entitled: Demonstrate understanding of the chemistry used in the development of a current technology. However, the study found good scope for covering much of the assessment (with some adaptations) that is needed for an integrated-STEM course of the kind described in Appendix A at all three levels of NCEA for Technology. These standards all sit within the “technology practice” strand of Technology; Appendix B shows the matrix of technology generic standards for level 1 (Year 11) NCEA.

In their discussion of the results, Granshaw and Hall suggest that although the New Zealand Curriculum (2007) provides support for the development of cross-curricula courses in its front-end description, NCEA lags well behind the encouragement provided by the New Zealand Curriculum. The exception appears to be Technology. The conclusion reached by the writers is that cross-curricula course design has not been at the forefront of the thinking of those who have been involved with the design and review of NCEA standards. Standards have been designed subject by subject, meaning that possible significant or deep cross-curricula connections made by students (Technology excepted) are likely to go unrewarded by NCEA as it stands at the moment. Paradoxically, as noted by Lipson (2017), NCEA has been promoted on the belief that it provides teachers with the opportunity to design courses that cross boundaries. In a presentation to school principals and officials from the Ministry of Education and the New Zealand Qualifications Authority (NZQA), Hall posed the following question: “Where in the current design of NCEA is there a systematic consideration of the linkages between the different parts of the NZ curriculum, both within curriculum areas/subjects and across such divisions?” (Hall, 2016, p. 6). Until the Ministry and NZQA engage seriously with this question, progress towards cross-curricula

integration is likely to be limited and superficial. Fortunately, integrated-STEM courses with Technology as the principal subject, have a life under NCEA.

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## APPENDIX A

### Indicative Specification for an Integrated-STEM course

<p><b>Course title:</b></p> <p>Technology with Mathematics and Science — Developing Design Solutions</p> <p>(Comment: The indicative course title identifies Technology as the principal subject with contributing content and skills coming from Mathematics and Science.)</p>
<p><b>Statement of the purpose / rationale for the development of the course:</b></p> <p>The aim of the course is to give students in the senior secondary school the opportunity to undertake a design and development project that will deepen their theoretical and practical knowledge of Technology and gain a strong appreciation of the significance of cross-curriculum learning for problem solving and creative design. The course could be adapted to either students who intend to proceed to tertiary education or students who are following a vocational pathway in schools.</p>
<p><b>Course description:</b></p> <p>The course involves students developing design solutions by drawing upon and integrating Technology, Mathematics and Science subject knowledge and skills. Although the course has an applied focus it still requires students to consider theory and display understanding of the properties of materials being used. Students will need to develop the skills associated with the tools/equipment/digital applications that are relevant for creating a solution. Students will also be expected to demonstrate understanding of research and enquiry processes generally associated with problem-solving and systematic investigation. The intention is that design problems will require</p>

solutions involving one of the following:

- A technological/engineering outcome such as an artefact, a digital application, a system process, or an architectural environment.
- A conceptual design such as a model that is, for example, digital, oral, graphical or materials based.

Examples of contexts where such design problems may be located could be: architectural, biological, chemical, digital, electrical, environmental, marine, mechanical, or structural in nature.

### **Learning objectives:**

Students will demonstrate the ability to:

- Plan and develop solutions to design problems in an integrated-STEM context
- Integrate learning from a combination of knowledge bases (i.e. Technology, Mathematics, Engineering and Science)
- Reflect critically upon how the integration of knowledge from the STEM subjects has guided the design and development process.

(Comment: The above learning objectives are broadly stated but, as the course unfolds, can be translated into more specific learning objectives to further clarify for students what is expected of them.)

### **Course content and sequence:**

(Comment: This is hard to specify in the absence of detail about the knowledge that is to be drawn upon from the contributing disciplines and the associated problems or designs that students could tackle that draws upon this knowledge.)

### **Teaching and learning strategies:**

Cross-disciplinary teaching and learning strategies that would be appropriate for an integrated-STEM course are likely to include at least some of: team teaching; a mix of traditional instruction, guided learning, and discovery learning; students working in groups and giving progress seminars to their classmates; students conducting systematic research, including online searching of data bases; use of online instructional programmes; guest stakeholder presentations from relevant industries and professions; interviewing by students of stakeholders that are relevant to their projects.

### **Assessment framework:**

For the New Zealand context, students will be assessed against a selection of NCEA achievement standards drawn from the relevant contributing disciplines. Emphasis will be given to performance on the generic achievement standards within the Technological Practice Strand of the Technology learning area. An example of the relevant Technology strands for NCEA Level 1 (Year 11) is given in Appendix B; the standards of particular relevance are shaded for the convenience of the reader.

For the design and development project, students could be required to submit a portfolio setting out descriptions, analyses and formulations relating to the selection, research, design, and development of the project outcome. For a group project, consideration will need to be given to the method by which each student's contribution to the work is assessed. In addition, the work should be conducted in stages with reporting from students at specified milestone dates. It is essential that students' progress is periodically supervised and monitored for both formative and summative assessment purposes.

The assessment should include a focus on how well students have integrated the knowledge and skills from all contributing subjects. A direct assessment by teachers of

the important integrative links made by a student is an obvious inclusion. Students could also be required to include in their portfolio a reflective statement of how the different knowledge areas have been drawn together.

**Ongoing and end-point course evaluation:**

The foci of the evaluation will include: Student learning in relation to the learning objectives of the course; student experience of the course; stakeholder experience of their contributions.

Strategies will include: Periodic and end-point feedback from students on their course experience (e.g., quality of instruction and guidance; value of the project for their learning). Interviews with stakeholders on their experiences and course features that they thought valuable and less valuable. Analysis of student work, including the formal assessment of student discipline knowledge and portfolio. Peer evaluation and a debriefing meeting for the teaching team.

**APPENDIX B**

**Level 1 NCEA Generic Achievement Standards**

Curriculum Strand		
Technological Practice	Technological Knowledge	Nature of Technology
1.1 AS 91044 Internal 4 credits Undertake brief development to address a need or opportunity	1.5 AS 91048 External 4 credits Demonstrate understanding of how technological modelling supports decision-making	1.9 AS 91052 Internal 4 credits Demonstrate understanding of the ways a technological outcome, people, and social and physical environments interact
1.2 AS 91045 Internal 4 credits Use planning tools to guide the technological development of an outcome to address a brief	1.6 AS 91049 External 4 credits Demonstrate understanding of how materials enable technological products to function	1.10 AS 91053 External 3 credits Demonstrate understanding of design elements.
1.3 AS 91046 Internal 6 credits Use design ideas to produce a conceptual design for an outcome to address a brief	1.7 AS 91050 External 4 credits Demonstrate understanding of the role of subsystems in technological systems	1.11 AS 91054 Internal 4 credits Demonstrate understanding of basic human factors in design
1.4 AS 91047 Internal 6 credits Undertake development to make a prototype to address a brief	1.8 AS 91051 Internal 4 credits Demonstrate understanding of how different disciplines influence a technological development	1.12 AS 91055 Internal 4 credits Demonstrate understanding of basic concepts used in manufacturing
		1.13 AS 91056 Internal 4 credits Implement a multi-unit manufacturing process



# From High to Low Voltage: A genre approach for teaching to write about designing

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Using language adequately within specific content areas can be challenging for students. In this study a curricular design was developed through a series of trials, with the aim to arrive at general principles for a pedagogy that helps students to write about an engineering (electronics) design. The curricular design was theoretically anchored in ‘genre pedagogy’ and in the pedagogy of engineering and technology. The interventions were carried out by one experienced teacher in one course, during three consecutive cycles of trialing and improving the curricular design. Qualitative data were analyzed using theory-based codes as well as codes that emerged from the data. The resulting design principles for teaching to write about (engineering) design are categorized as: setting a functional writing task, scaffolding the writing process, and a relevant, complete and feasible focus on language. For each of these, specifications are described.

*Key Words: design, language, pedagogy, writing, genre.*

## 1. INTRODUCTION

Language related problems that students face in engineering and technology education (ETE) are not well researched (Van Dijk & Hajer, 2017). Teaching the language of technology brings about specific challenges. Students and teachers may think that language is less important in ETE than in other school subjects and writing in ETE suffers from a lack of canonical text types, such as the experimental research report in science. This study provides an entrance into the solution of this problem.

The problem at stake became manifest in one institute for tertiary education where students were expected to write a ‘design report’ about designing a torch. According to the teacher, Bert, the students lacked the motivation to write and their reports were generally of mediocre quality; unclear and not resembling professional electronics engineers’ texts. Yet, he felt that the writing task could not be avoided without affecting course content. It was a prerequisite for assessing their understanding of the electronics involved as well as the design process. For this reason, he needed a pedagogy that would guide students proficiency to write these specific texts.

The research question that guided this study was: What are characteristics of a pedagogy that helps students to write about designing?

## 2. THEORETICAL FRAMEWORK

Approaches to alleviate problems at the intersection of content and language have been developed for five decades (Brinton, Snow & Wesche, 1989; Short, Vogt & Echevarria, 2011). However, such approaches may fail to target language that is specific for a subject such as science or technology, a problem that can be addressed through genre pedagogy (Rose & Martin, 2012; Van Dijk, 2018).

Genre pedagogy is an approach that departs from the assumption that learners benefit from an explicit focus on ‘how language works’. The word genre reflects the functional nature of text analysis, whereby language is seen as ‘meaning making’ in cultural contexts and situations. Typically, a ‘teaching learning cycle’ (TLC) is used. Exemplary texts are deconstructed, which is followed up by joint construction of texts by the teacher and the students, and lastly by students’ independent writing (Rose and Martin, 2012).

Genre pedagogy uses Systemic Functional Linguistics (SFL) as an underlying theory to explicate how meaning is made (Halliday, 2004). Main categories of analysis are field, tenor and mode. Field refers to the ideas that are expressed, tenor refers to tone and other aspects of language that are related to the social context, and mode refers to the verbal or written character of the text and to text organization and graphical devices that are used to make meaning. Knapp and Watkins (2005) distinguish between 5 types of genres: describing, explaining, instructing, arguing and narrating. Each of these has its own rhetorical functions and register.

A few examples of genres that are specific to ETE are listed below.

- An explanation of the working principles in a system, meant for further development by engineers.
- A product description meant for consumers.

A manual with step by step instructions for maintenance work by engineers.

### **3. METHOD AND CONTEXT**

The study was carried out using an Educational Design Research (EDR) framework (McKenney & Reeves, 2012). EDR typically produces an empirically tested design as a solution for a problem in a specified educational context. The process of designing and testing relies on the use of existing theory, and in turn, EDR studies contribute to new theory about teaching and learning.

This study was carried out at an institution for secondary teacher education, in a seven week course on electronics. Bert had extensive experience in teaching as well as in electronics engineering. Bert and the researcher collaborated during three years to develop prototypes A, B and C. Students were participants in an initial teacher education program (year two), mostly aged between 22-50, some without much teaching experience and others with extensive experience.

Data consisted of:

- Transcribed interviews and sessions for lesson design with the teacher
- Observations and videos of lessons
- Transcribed interviews with students prior to lessons and afterwards
- Filled out questionnaire for students, about their experiences with the interventions
- Students’ written products

Computer assisted coding of data (in Atlas.ti) was carried out on three dimensions of design and delivery: Motives for setting writing tasks about practical work, Instructional strategies and Aspects of ETE language. For each of these, an initial set of theory-based codes was chosen. During the coding process this set was supplemented with codes for important themes that emerged from the data.

### **4. RESULTS**

#### ***4.1 Main characteristics of the interventions***

The sequence of activities that was used throughout testing and adapting the prototypes was as follows:

- A. A brief whole class discussion about the function of writing for learning in ETE.
- B. Deconstructing exemplary texts, for instance an explanation (including a circuit diagram) of the working principles of an electronic design.

- 1) In pairs: Reading a good example and making comments about qualities of the language.
- 2) Discussing positive comments by the teacher. These comments were compiled with the aid of an instrument that lists (and gives examples of) aspects of language that can be important in design texts. The instrument was called PRIL (box 1), which stands for Practical Report Inventory of Language. It was meant to provide technology teachers with targets for language development. The items were chosen on grounds of relevance for science and technology, feasibility for use by technology teachers and completeness in terms of field, tenor and mode.

Box 1: Items in PRIL instrument (short version and without examples)

- Text organization with sub headings
- Combination of text, graphic representations and formulas
- Coherence within paragraphs
- Devices that make text coherent, such as ‘signaling words’ (because; therefore; firstly; etc.)
- Use of concepts.
- Difference between meanings of words in daily life and in ETE
- Use of verbs that belong to the topic.
- Choice of tense.
- Use of standard word combinations.
- Extent to which the writer makes himself visible in the text
- Expressing personal emotions, evaluations and judgments with appropriate strength.

C. Joint

construction of a text by the teacher and the students. Students were given a fragment of a mediocre electronics design report and asked to rewrite it in pairs, in such a way that Bert could see ‘real time’ what was being written. This gave Bert time to prepare feedback, which was shared with the whole class. Improvements were suggested by Bert and the students.

D. Independent writing by students.

E. Peer feedback in pairs, whereby students targeted particular aspects of language that they want to receive feedback on.

The entire intervention, A to E, lasted about two hours.

#### **4.2 Prototype A**

This sequence of activities was maintained throughout the study because of positive evaluations by Bert and his students. What students appreciated was the explicitness about useful language. The evaluations were backed up by observations of lessons and analysis of video’s. Findings confirmed that the interventions were generally perceived as useful by participants from the perspective of learning the content. However, during the trial of prototype A two problems emerged. Firstly there was a problem with explication of aspects of ETE language and secondly with the text to be produced.

#### ***Bert’s knowledge about ETE language***

The choices that Bert made from the PRIL instrument during enactment of prototype A were consistent with findings that ETE teachers often focus on specialized vocabulary. With regard to Bert’s knowledge about text organization, a remarkable development occurred during enactment of prototype A (box 2).

Box 2

Bert during an stimulated response interview in which he reflected on his instruction:

*Here I thought, I'll give them a nice cue to start off their texts. I was really happy with that. I related at that moment, live, the start of their texts where it is about the description of the circuit, it's working principles, to the way those diagrams are drawn and read: the waterfall principle for reading. That is a beautiful anchor, I thought. I must keep using that, I thought.*

The waterfall principle, according to Bert, implies that circuit diagrams are drawn and read from high voltage to low voltage. Bert and his students discovered that this is a functional way to organize the accompanying text too.

During enactment of prototype A, Bert was dismissive about other aspects of ETE language. For instance, he felt that achieving cohesion in reasoning by means of 'signaling words' was not important. However, when the students' reports were analyzed he expressed eagerness to address how 'chains of reasoning' could work in the students' texts.

### 4.3 Prototype B

Box 3 illustrates changes in Bert's knowledge and beliefs about aspects of language between enactment of prototypes A and B.

Box 3

Bert during activity B4 (deconstruction of a professional text)

So what you see, is that a chain of reasoning emerges, that can be followed really well, also because it has a proper coding [points on the screen to R2] that is also used in the circuit diagram, and because certain signalling words are used.

Standard word combinations [reads some examples from the text aloud] are important in technology language, to communicate the message and to avoid misconceptions. 'The voltage flows' is something that one hears regularly and one might ask whether that demonstrates a misconception. Voltage is 'across'.

Bert had now included specialized forms of reasoning with the aid of '*signaling words*'; words (verbs and nouns) and their combinations. However, enactment of prototype B revealed a problem that had been discussed with Bert from the start and for which no solution had been agreed upon yet. This was a lack of clarity about the genre that the students were supposed to produce, which Bert had called a 'design report'.

Box 4 illustrates how, in Bert's instruction, characteristics of the genre seemed to be at odds with each other.

Box 4: Bert during deconstruction of an example text

*He doesn't write in a style like, 'well, I've made that circuit and it went kind of alright, but...' That kind of process language is not appropriate in these kind of articles.*

Bert during a comment about a student who had included a series of circuits with increasing complexity in his report:

*You could include those steps in thinking, to make it easier for yourself.*

The essence of many of Bert's comments was that 'process language' would not be appropriate in the students' reports, whereby 'process' referred to the students' learning process. Contrary to that, Bert said that he needed information about the students' learning process, which would call for a personalized tone. An analysis of student's design reports by Bert and the researcher confirmed that these conflicting characteristics led to an unclear amalgam of genres. A redesign was required that could specify functional aspects like context of the text to be written and appropriate language use (tone, field, mode).

#### 4.4 Prototype C

A solution was inspired by Barlex (2007), who argues for a minimally invasive approach for writing design portfolio's. In prototype C students were asked to write a design portfolio, consisting of three components: a product description, a process description and a job bag (table 1).

Table 1: components of the design portfolio

Component	Main content	Targeted audiences
Product description	A circuit diagram and an explanation about the working principles (400 words).	Readers of an electronics magazine.
Process description	Argumentation for solutions that were chosen for the most difficult design problems that were encountered (200 words)	The teacher who needs to assess whether a student can develop his own solutions for design problems.
Job bag	Loose collection of sketches, drawings, screen shots from online component catalogues, web texts, etc.	The student himself as designer, for possible later use for similar designs. The teacher who needs to assess whether the student has searched and found existing solutions in appropriate places.

Bert was asked to identify characteristics in a sample text for each component. The result is summarized in table 2.

Table 2: Characteristics of the design portfolio, according to Bert

	<i>Product description</i>	<i>Process description</i>	<i>Job Bag</i>
<i>Text organization (modes)</i>	<p><i>Sequence: Circuit diagram&gt;function&gt;working principles</i></p> <p><i>Chains of reasoning about function of components and sub systems (such as power system). Text sequence is from high voltage to low voltage.</i></p> <p><i>Precise referencing between diagram and text, using electronics symbols.</i></p>	<p><i>Sequencing text according to time: First I tried, then ....</i></p> <p><i>Argumentative text organization (I used component X for reasons Y and Z.)</i></p> <p><i>Increasingly complex circuit diagrams that show progress during the design process.</i></p> <p><i>Precise referencing between diagram and text.</i></p>	<p><i>Random organization</i></p> <p><i>Little text</i></p> <p><i>Diagrams copied from the internet and data sheets of components.</i></p> <p><i>Block diagrams</i></p> <p><i>Sketches</i></p>
<i>Words and word combinations to realize the content (field)</i>	<p><i>High density of specialized vocabulary, both verbs and nouns (regulating, capacitor). Standardized word combinations (voltage across)</i></p>	<p><i>High density of specialized vocabulary.</i></p> <p><i>Standardized word combinations</i></p>	<p><i>URL's</i></p> <p><i>Specifications</i></p>
<i>Tenor</i>	<i>Depersonalized tone</i>	<i>Personalized tone</i>	<i>Varying tone</i>

Table 2 illustrates that Bert could now combine his knowledge about language with a deeper insight into the purposes of writing about design. Based on this analysis, learning materials were constructed to share this knowledge with his students. Written evaluations of these interventions by students revealed that they were predominantly positive about the clarity of the writing task and the support given (box 5).

Box 5: Evaluations by students that are exemplary for all evaluations.

- It was quite quickly clear to me what had to be done. Especially after seeing the examples and reading the assignment I knew what had to be done.
- Now I know better how I will be judged, how the teacher looks at the portfolio.
- This approach has given me some concrete ideas. Because he described the way of writing. The focus points make you think about the way you write. I always benefit from examples.
- Clear. ++ But I'd rather received this information at the start of the course.
- The use of signaling words was good; what do you want to see in the report? But for practicing with writing, one could have used an easier circuit.

Cross case analysis revealed that students in all cases evaluated the interventions as positive for their learning, but only after enactment of prototype C they specified aspects of language that had been addressed and that had helped them. Moreover, Bert asserted that their written products were substantially better than earlier products. The portfolios were shorter, more concise, it gave him insight in the students' learning and design process and the product descriptions resembled professional engineers' texts.

## 5. CONCLUSIONS AND DISCUSSION

This study demonstrated that an ETE teacher can integrate a language perspective in his teaching about designing. The three main characteristics of the pedagogy that was found to be useful, are: A) setting a functional writing task, B) scaffolding the writing process and C) relevant, feasible and complete forms of knowledge about language that are explicitly addressed.

### **5.1 Setting a functional writing task**

There is no canonical form of writing about design. It is challenging for ETE teachers to set a task for writing about designing that is functional. This means that the task resembles, at least partly, a professional genre in engineering, but it should also give students a space to elaborate on the learning and designing process (Barlex, 2007; Kimbell & Stables, 2008). The writing task that was developed in this study, based on ideas by Barlex (2007), combines these functions. It is a portfolio consisting of a product description, a process description and a job bag.

### **5.2 Scaffolding the writing process**

The teacher's motives for setting a writing task and the aim of each activity are clarified, because writing is not always perceived as a useful activity by students in ETE classes. Episodes of deconstructing exemplary texts, joint construction and independent writing (the TLC) are useful and feasible as scaffolds. Separate components of the design portfolio are scaffolded separately. For a product description authentic examples are useful, whereas for the process description and the job bag, students' written products are useful as models. A form of joint construction needs to give the teacher immediate insight in the students' text production and time to prepare fast feedback.

### **5.3 A relevant, complete and feasible focus on language**

The function and *relevance* of language is paramount. The central questions are: how does language work in specific technology and engineering practices, such as in designing and how does it work in ETE? Talk about language in ETE classes can easily become fuzzy, whereby the focus is on content without clarifying how meaning is made through specific language resources. SFL can provide a systematic and complete (in terms of field, tenor and mode) framework. All three register variables have proven to be important in the components of a design portfolio, as demonstrated in table 2.

ETE teachers and students are not linguists and genre pedagogy can confront subject teachers with overly challenging meta-language (Holmberg, 2009). A *feasible* selection of knowledge about language is needed and technical terms such as 'cohesive devices', 'deconstruction' and 'field, tenor and mode' can be replaced by more familiar terms. ETE teachers can learn to use feasible meta language, provided that they receive support by language specialists who help to clarify how meaning is made in ETE. Not all aspects of ETE language are equally important in all instances of teaching. Furthermore limitations of cognitive load demand a focus on only a few aspects of language at a time. An instrument, such as PRIL, that lists and explains aspects of language is helpful to find a focus.

### **5.4 Further research**

Research by linguists in collaboration with engineers is needed to improve our understanding of characteristics of the language of designing. Studies in the philosophy of technology have already revealed unique characteristics of knowledge in technology (Norström, 2015; Ryle, 1949; De Vries, 2013), but there is still a leap to be made from explicating knowledge to explicating language characteristics. In this study a few of such characteristics have been explicated by one teacher and one researcher. This can only be seen as a first exploration of this issue (Hajer, 2018).

This study was carried out in an institute for tertiary education. Research in primary and secondary ETE is needed to find out whether writing about designing can be scaffolded in a similar fashion in those contexts.

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# Making it Work: A Case Study of Canadian Intermediate Technology Educators' Pedagogical Classroom Practice

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Building on the work of the Technology Education Teaching Framework as discussed in my recent dissertation, this paper aims to explore the innovative and creative practice of teaching intermediate (grades 7-9, 12-14 years of age) technology education within the jurisdiction of Newfoundland and Labrador, Canada. The paper will begin by briefly discussing the context of intermediate technology education in Newfoundland and Labrador, Canada. Specifically, the paper will focus on the framework's teacher experience construct in relation to classroom teaching by exploring how individuals' experiences and beliefs influence the teaching of intermediate technology education. After a short review of the literature and summary of research methodology the results will be presented as a detailed teaching vignette based on three observations in an intermediate technology classroom. A discussion of teacher perceptions, pedagogical approaches, curricular alignment, pedagogical content knowledge, teacher-student relationships, and best practice will be discussed within the context of systemic curricular marginalization and teacher professionalism as outlined in the Technology Education Teaching Framework. Intermediate technology education teachers in Newfoundland and Labrador report working from a marginalized position within the K-12 education system. Regardless of this reported marginalization, the data presented in this paper highlights their ability as highly skilled and competent technology education teachers that have the capability to build the human capacity of their students by cultivating imagination and innovation on a daily basis.

*Key Words: Technology education, Classroom teaching, Technology pedagogy.*

## 1. INTRODUCTION

The growth and development of technology education over the last three decades within the Newfoundland and Labrador context is the combined result of multiple forces and mandates that have sought, and continue to seek to use public technical education as a means to meet political and economic ends (Haché, 2007; Tucker & Maxwell, 1995). The initial curricula was designed to meet the criteria of the 1992 Royal Commission on public education in Newfoundland and Labrador by developing technology education courses that would replace computer and industrial arts courses and allow students "... the opportunity to explore problems which have complex, multidimensional components and develop technological solutions integrating a variety of technological principles, tools and resources" (Tucker & Maxwell, 1995). While many of the courses available to students in Newfoundland and Labrador still maintain this approach, other initiatives based on economic and political concerns have also shifted the focus of a portion of the curricula towards a primarily skills and training based model (Haché, 2007). Most recently, external pressures and major federal government funding have again initiated a shift as computer programming ("coding") and digital skills are perceived as areas essential for continued economic success (Innovation Science and Economic Development Canada, 2017; Newfoundland and Labrador Department of Education and Early Childhood Development, 2018b). As such, there has been a move to develop curricula with an explicit focus on computer related technology (Newfoundland and Labrador Department of Education and Early Childhood Development, 2018a).

While these trends appear to mirror the economic, political, and social influences on technology education reported across Canada and other modern international educational jurisdictions (Haché, 2006; Hill, 2009; Jones, Bunting, & de Vries, 2013) there has been a dearth of empirical research on the teaching of technology education within the Newfoundland and Labrador context. Therefore, this study was initiated as the beginning of a larger technology education research agenda and to add support for the existing professional networks and

pre-service programs already established in Newfoundland and Labrador. In particular, this study was positioned to investigate the teaching of intermediate (grade 7-9, 12-14 years of age) technology education within the Newfoundland and Labrador context. This mandatory curriculum was first implemented in the early 2000s with subsequent additions and revisions over the preceding decade. Currently, there are four modules that touch on communication, production, control, and energy and power technology. Each module is allocated 26 hours of instruction as per the Newfoundland and Labrador Program of Studies (“Program of Studies,” 2016). If these modules are taught as published, students should have experiences in designing, making, evaluating, and re-developing solutions to technological problems within a larger framework of technological literacy. As there was anecdotal evidence to suggest curricular marginalized in relation to more traditional subject areas, this study sought to gain an in-depth understanding of the experiences of intermediate technology education teachers.

## 2. LITERATURE REVIEW

Teachers’ experiences and beliefs have been reported to affect student assessment, epistemological assumptions about technology and technology education, praxis, and pedagogical content knowledge (Hartell, Gumaelius, & Svärth, 2015; Jones & Compton, 1998; Männikkö-Barbutiu, 2011; Norström, 2014). Although a Diploma in Technology Education is available from Memorial University of Newfoundland, there is no requirement for teachers to hold this diploma in order to teach technology education in the province. As the Newfoundland and Labrador English School District (NLESD) has discretion in hiring, and due to teacher supply and availability issues, individual teaching preference, and possible administrative staffing pressures, it is quite common, especially in the intermediate grades, to have a wide variety of teachers assigned to technology education. This diversity of teachers within the local context is mirrored by a survey of the literature that identified three potential types of technology education teachers; specialists, non-specialist, and in-experienced teachers (Bungum, 2006; Copeland & Gray, 2002; Hartell et al., 2015; Jones & Compton, 1998; Norström, 2014; Parkinson, 2001; Williams, 2008).

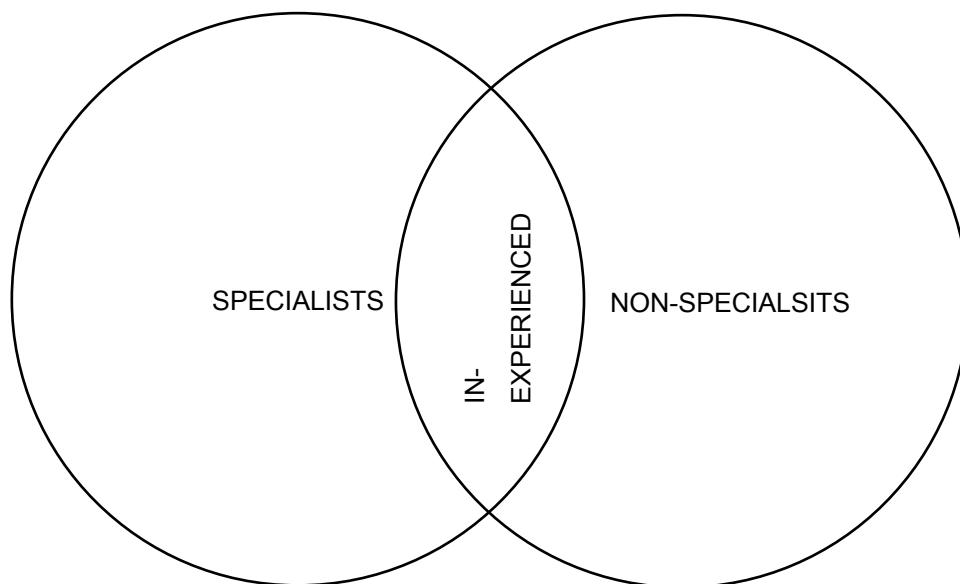


Figure 1. Technology education teachers' categorization continuum.

Specialist teachers, with specific technology education qualifications, have been reported in the literature as having a mix of skill and understanding in this domain. Hartell et al.'s (2015) study of 88 Swedish technology education teachers found that specialist teachers reported having higher teacher-efficacy in relation to student assessment than their non-specialist counterparts. Norström (2014) on the other hand reported that self-identifying technology education teachers' assumptions concerning technology and technology education did not differ much from non-technology education teachers' views.

The idea of non-specialist teachers also emerged as a possible category from the literature. Many studies do not report the detailed educational backgrounds of teachers. In Copeland and Gray's (2002) study, they simply reported that the average Maryland technology education teacher had a bachelor's degree and some post-secondary study with no discussion of their technology qualifications. Williams (2008) study on professional development for existing technology and design teachers' in Western Australia, is also silent on the teachers' educational background. Along with studies that allowed teachers' to self identify (Norström, 2014), it is evident non-specialist teachers are engaged in teaching technology education.

In-experienced teachers, with general teaching credentials and no experience in technology education or pre-service teachers, were explicitly found throughout the literature. Bungum's (2006) cross-case study involved interviewing and observing 14 teachers from 9 Norwegian schools with no background in technology education. Even with support from the project, some teachers still developed misconceptions about the nature of technology and technology education in relation to their interpretations of the curriculum and teaching experiences (Bungum, 2006). Parkinson's (2001) study of pre-service teachers also found that childhood misconceptions concerning technological principles can remain even after experiences in technology education teacher programs. A lack of understanding and confidence in the what, how, and when components of teaching technology education were also reported by Männikkö-Barbutiu (2011).

While this view of teachers' qualifications is far from complete, it did provide a good point of reference for investigating the experiences of intermediate technology education teachers within the Newfoundland and Labrador context as they tend to fall within this continuum. Rather than quantifying the distribution of teachers on this continuum, the study sought to develop a case study of the day to day practices of experienced specialist or non-specialist intermediate technology teachers.

### **3. METHODOLOGY**

#### ***3.1. Research Questions***

The main research question that guided the study was: What factors support or hinder the capability and capacity of intermediate technology education teachers in Newfoundland and Labrador? For the purpose of this paper the following sub-question will be considered in detail. How do individuals' experiences and beliefs influence the teaching of intermediate technology education?

#### ***3.2. Methodology***

A qualitative exploratory case study was designed to capture the thick rich detail of teachers' experiences teaching intermediate technology in Newfoundland and Labrador. Case study was defined as "... an in-depth description and analysis of a bounded system" (Merriam & Tisdell, 2016, p. 37). The unit of analysis or case was the capability and capacity of intermediate technology education teachers in Newfoundland and Labrador. The boundaries for this system included schools offering intermediate technology education, teachers assigned to the subject area, and the jurisdiction of the NLESD.

#### ***3.3. Sampling***

Purposeful typical sampling was used to recruit participants. To be considered to participate in the study teachers had to have 1) three or more consecutive years teaching intermediate technology education, 2) be teaching intermediate technology at the time of the study, and 3) work in the Avalon East or West regions of the NLESD. Nine of 31 potential teachers were identified through an initial online questionnaire as meeting this criteria. Seven agreed to conduct interviews, two agreed to participate in a set of three classroom observations

and an anchor interview. Two principals also agreed to participate in interviews. Therefore, a total of 11 participants took part in the study.

### **3.4. Data Collection and Analysis**

Data was collected through an online questionnaire, teacher and administrator interviews, and a series of classroom observations. The observation session data and anchor interviews have informed the results discussed in this paper. Thematic analysis as defined by Braun and Clarke (2006) was used as the framework to develop the thick rich description needed to explore the case in question.

## **4. RESULTS**

The observation sessions with intermediate technology teachers allowed for the development of detailed vignettes that described the in situ teaching methods and class dynamics of the participating teachers. The following vignette is presented as an example of an experienced specialist technology education teacher in action.

Mr. Spock is a veteran technology education teacher with over 20 years' experience. He has taught at both the secondary and intermediate level throughout his career and during the time of this study was teaching the Newfoundland and Labrador grade 8 production technology curriculum at a large urban intermediate school. He was the only teacher assigned to this area and therefore was responsible for all four sections of the course. Grade 8 production technology focuses on residential construction problems. The vignette presented below was observed during the last unit of study for the course and involved students' prototyping wood-frame construction structures to meet the specifications of a design challenge.

Mr. Spock's approximately hour-long classes followed a similar three point pattern in each iteration. First, he opened with direct instruction with the use of project exemplars, open class discussion, project expectations, and safety reminders. Second, the class would break into small groups in the fabrication area, and began to work independently on their projects. At this point, Mr. Spock generally engaged in small group discussion, one-on-one instruction, and logistical tasks for the remainder of the class. Third, he always took time at the end of every class to reinforce class safety and cleaning routines.

Mr. Spock generally started each class by explaining the remaining timeline for the completion of the prototype construction, and reviewing the procedures for various component construction. Rather than relying on paper or digital plans for this explanation, he demonstrated the final expectations by showing examples of the actual artifacts – a previously constructed foundation, a constructed wall, and the individual components of a wall. As he worked through these different components, the class engaged in discussion to clarify their tasks and procedures. Mr. Spock relied on analogies to help the students understand the concepts of wood frame construction such as thinking about the walls as a sandwich with the top and bottom plates representing the bread and the studs representing the filling. Moving forward, he introduced the idea of jigs as tools that make doing repeatable tasks easier and more precise. As an example, he set up a simple mitre box jig by clamping a small piece of plywood at the eight inch mark, past the 90 degree slot in the mitre box. He then demonstrated how they could slide a longer piece of stock until it stops against the plywood to cut accurately each time. Mr. Spock explained that without this jig, they ran the risk of constructing non-parallel walls that would be difficult to assemble. After a couple of follow-up questions, he sent the class into the fabrication area with the myriad of standard safety reminders that are required for working in such an environment.

The small group/one-on-one instruction phase of the class started as the students' moved into the fabrication lab. Students started turning on air compressors for the pneumatic nail guns, while Mr. Spock began cutting eight foot strips of 3/8" pine on the table saw to replenish the class' material supply. The combined noise of voices and running equipment filled the room for the entire class. Students worked in groups of three or four around the fabrication lab's work benches. Through the year, Mr. Spock has built up consistent routines and although it is a loud environment, it was very orderly. Students worked independently and asked for help from their peers, or Mr. Spock. After cleaning up, a group of girls close to the table saw asked Mr. Spock a question about the placement of their studs. He asked the group to get a speed square, measuring tape, and pencil. After

they retrieved the required tools, Mr. Spock explained the best procedure for laying out a wall. He placed their top plate and bottom plate together flat on their bench, and asked them to mark two inch increments on the bottom plate. As one of the students started to do this, Mr. Spock explained that they will line up both plates and use the speed square to draw a 90 degree line at each measurement mark. With an addition of an “x” on the left side of each line they will be able to match up and parallel their studs before securing them with the nail gun. This type of approach was continued throughout the entire class as Mr. Spock moved from group to group assisting and answering questions along the way.

As the class was coming to an end, Mr. Spock moved into the third phase of his class routine. With approximately five minutes left, he addressed the class and asked them to start cleaning up their workspaces and to label and store their projects in a safe location. Because the room is used by four different grade 8 production technology classes, this was a very important part of the final routine as it can be very easy to misplace or mistakenly use other students’ supplies and components. As the class began this process, the background noise started to subside. As each group finished securing their area, they moved back into the design space to gather their personal items before moving to their next class. After the students left, Mr. Spock related that he thought at this level it was very important to pique the interest of the students because of the possible longer range impact it could have. He related several stories of former students that excelled in related areas, such as robotics in high school, and that he believed the seed of that interest was sparked or encouraged through the intermediate program.

## 5. DISCUSSION

The observational data shed light on the actual practice of teaching intermediate technology education within the Newfoundland and Labrador context. The emerging themes were used as guideposts in the development of a larger *Technology Education Teaching Framework* that also factored in aspects of professional development and leadership in understanding teachers’ perceptions of technology and technology education (Gill, 2017). In particular, the classroom observations helped solidify the *teachers’ experience construct* as illustrated in figure 2. Teachers’ classroom experiences, teaching approach, pedagogical content knowledge, formal and informal educational background all affected their perceptions of technology education and classroom practice. These perceptions were also framed within the context of systemic curricular marginalization and teacher professionalism as it emerged from the data. Three themes related to hindering teaching were supported by the observation data while four themes related to helping teach intermediate technology education emerged.

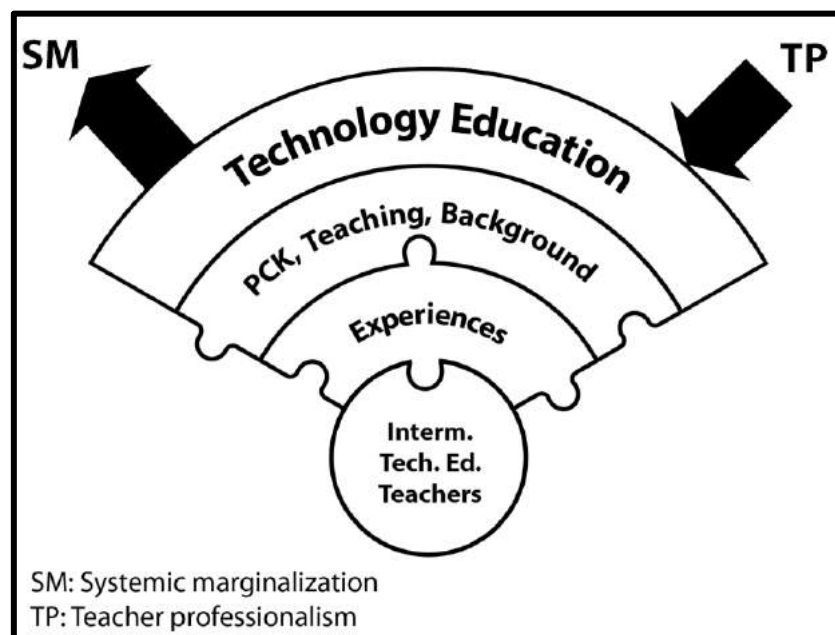


Figure 2. Technology Education Teaching Framework -Teacher Experience Construct

The three hindering themes relating to time, space, and resources that emerged from the observation data fell within a bigger idea of systemic marginalization. Interview data revealed that the scheduling of intermediate technology education is an issue. As so little time is allocated for intermediate technology education (26 hours per module) it is not uncommon for weeks to pass between classes thereby causing major continuity problems. This was evident in scheduling observation periods in which it required two to three months to actual schedule three sessions. Both observation participants related concerns about space during the observation sessions as well. While the other participant noted that having his classes scheduled in the school's library was a distraction as other teachers and students used the space concurrently, Mr. Spock, reported concerns about space in a different way. While the class I observed had twenty-four students, Mr. Spock spoke about safety concerns with other larger classes. It was noted in the general interview data that several teachers have stopped offering grade 8 production technology due to space limitations and safety issues. While Mr. Spock had a large fabrication area, he noted that in his classes with approximately thirty students he did have concerns about classroom management and safety. The idea of access to resources was also observed in Mr. Spock's classroom. In his design area, every available space was filled with computer work stations. While he had enough for every student in the observed class, he noted that he did not have enough for his largest classes which caused multiple administrative and teaching issues. Moving from these hindrance themes, four helping themes emerged from the observation data: Teacher preparation, classroom routines, teacher knowledge and skills, and teacher-student relationships.

First, observation participants were always prepared for class. Whether it was the use of exemplars, rubrics, and assignment documents, or the preparation of materials, demonstrations, and physical space, teachers practiced effective instructional preparation. The development and use of classroom routines was the second mechanism that emerged from the observation data. A pattern of instruction emerged in the data which included short direct instruction, demonstration, and discussion, followed by a long period of independent student work and teacher facilitation, and final progress check-ins before the end of each session. It was evident by student behaviour that these routines were the norms and that each teacher had spent considerable time on this aspect. Third, the participating teachers were very knowledgeable and skilled in their subject area and demonstrated strong pedagogical content knowledge as well. Participating teachers employed a student-centered approach by letting student questions lead conversation, engaged in formative assessment practices, and demonstrating safe and precise technics. These exchanges and interactions emphasised real-world applications of the students' work by framing their conversations within that context. Fourth, the importance of developing good rapport and working relationships with students emerged from the data. This was apparent through the use of humour by both teachers, and in their individual interactions with the students. It was quite evident that both teachers held the developmental interests of their students at the center of their teaching. The data would suggest that the participants had an excellent handle on the intermediate technology education curriculum, and the experience and expertise to balance that with the reality of their schedule, space, resources, and students.

Reflecting on the question of how individuals' experiences and beliefs influence the teaching of intermediate technology education there appears to be evidence to suggest a relationship between the two. Hynes (2012) speculated about teachers' background knowledge and experiences effecting their teaching of the engineering design process in middle school, but was cautious to confirm his inference. While I am also cautious in my own evaluation, based on the data, I am optimistic that Hynes' (2012) inferences ring true within the Newfoundland and Labrador context.

Jones and Moreland (2005) identified knowledge of the characteristics, the conceptual and procedural aspects, the curriculum, student learning, and specific teaching and assessment practices in technology education as key to developing sound pedagogical content knowledge. It was evident from the observation data, that the participating observation teachers have a good grasp on how to teach this subject area. In addition, both teachers had the characteristics listed above, and in turn, demonstrated their pedagogical content knowledge through their teaching. While the sample for this study focused on experienced specialist technology education teachers, it is interesting to note that these findings were in contrast to Männikkö-Barbutiu (2011) conclusions that technology teachers with less experience can feel unsure of what, how, and when to teach things in technology education.

As teachers do not operate in a vacuum, their beliefs and classroom practice are shaped and influenced by multiple factors. How formal educational experiences, professional development and community support, and aspects of leadership interconnect to effect intermediate teachers perceptions of technology and technology education remain to be explored. While it has emerged that intermediate technology education teachers work from a position of marginalization within the Newfoundland and Labrador school system, the participating teachers demonstrated their competency and skill in providing their students' opportunities to design, make, evaluate, and re-develop solutions to technological problems within a larger framework of technological literacy.

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# Supporting Discourse using Technology-Mediated Communication: The Community of Inquiry in Design and Technology Education

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Despite the pervasiveness of Information and Communication Technology (ICT) in daily life, when ICT is used in the classroom its impact on learning and performance is mixed at best. However, ICT is linked with increased learning and performance in some contexts, for example when ICT can extend teaching and learning and enhance classroom practice (OECD 2015). The nature of design-based activity within the classrooms of Design and Technology (D&T) education provides an important context for this research. D&T develops the pupil-centred approaches and formative assessment practices of teaching and learning shown to have the strongest associations between the effective uses of ICT and enhancing classroom practice. Accordingly, this paper argues that supporting discourse is a precursor for the effective use of ICT in teaching and learning, and technology-mediated communication (TMC) provides a medium for supporting discourse between teachers and pupils within design-based activities. In conjunction with ICT, 'learning protocols' were implemented as both a pedagogical and technological approach for supporting discourse using technology-mediated communication. The research participants for this study include senior-cycle pupils ( $n = 87$ ) of D&T education and associated pre-service teachers ( $n = 7$ ) of Initial Technology Teacher Education (ITTE). This study comprised transcript analysis, teacher interviews, pupil focus groups, and surveys. In the context of supporting discourse using technology-mediated communication, the use of learning protocols created a shared language of understanding between teachers and pupils, and the frequency between teachers and pupils' use of learning protocols indicated evidence of an iterative and interactive process of teaching and learning within design-based activities. In comparing the frequency of learning protocols assigned by participants and the researchers the findings revealed there was a clear sense of hierarchical progression within the protocols and indicated that participants understanding of this 'meta-language' of progression increased across time and began to align more with the researchers understanding of learning protocols.

*Key Words: Design based activity; ICT supported learning; Interaction; Pedagogy.*

## 1. BACKGROUND

In Ireland, the Organisation for Economic Co-operation and Development (OECD) reported that in 2012, 98% of 15-year-old pupils have at least one computer at home, but only 64% of pupils reported that they use a computer, laptop or tablet at school. These findings show that despite the pervasiveness of Information and Communication Technology (ICT) in pupils' daily lives, ICT has not been as widely adopted in the classrooms of formal second level education. When they are used in the classroom, their impact on pupil learning is mixed at best. However, ICT is linked with better learning in some contexts, such as when ICT supports the pupils' engagement in challenging material, thus extending teaching and learning and enhancing classroom practice or helps pupils to assume a greater control over the learning situation, by individualising the pace of which new material is introduced or providing immediate feedback, pupils learn more. The strongest associations between the use of ICT and enhancing practice are pupil-centred approaches and formative practices of teaching and learning, which include individualised pace and feedback, collaborative learning, and project-based learning (OECD 2015).

The tendency to use the acronym of ICT instead of IT (Information Technology) reflects a growing recognition that information is framed in the context and imperative of communication and technology is a media of and for communication. Likewise, in education there is a growing recognition that ICT needs to be linked to conversations in social contexts and to communities of learning (Richards 2006) to create an integrated approach for effective ICT-supported environments. A conversational framework (Laurillard 2002), captures the essence of teaching as an iterative dialogue between teachers and learners while functioning on the following levels: a discursive, theoretical, conceptual level; and an active, practical, experiential level, i.e., the levels bridged between teachers and pupils while engaging in the process of critical thinking and reflection. A community of learning as defined by Ludwig-Hardman and Dunlap (2003) is a “group of people connected via technology-mediated communication, who actively engage one another in collaborative learner-centred activities to intentionally foster the creation of knowledge, while sharing a number of values and practices” (p. 10). It is clear that what teachers and pupils do with ICT and how they do it is a critical aspect in its meaningful integration in the classroom environment. However, if ICT is to make any real contributions to both teaching and learning, then supporting communication between teachers and pupils will need careful consideration.

## **2. DESIGN AND TECHNOLOGY**

As schools and teachers look to integrate systems of ICT in their classroom practice, Design and Technology (D&T) has continued to be recognised as a potentially rich environment to investigate their role in teaching and learning (McCormick 2004). This is because the nature of designing in D&T education is a conversational activity (Hamilton 2003, 2004; Hennessy & Murphy 1999; Murphy & Hennessy 2001), that draws on both teacher-pupil and pupil-pupil interactions within the social context. D&T education also has the potential to exploit ICT in a way that can transform both teaching and learning in a way that has not yet been done so far (McCormick 2004), as it affords pupils the opportunities for interaction, even when these are not made explicit by the pedagogic stance adopted by the teacher (Murphy & Hennessy 2001). Thus, D&T places conversation at the core of the educational process (Trebell 2007), providing both the context and the opportunities in which ICT can enhance practice through individualised feedback, collaborative learning and project-based learning.

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In Ireland, D&T has always met the challenge of keeping up with ICT (McGarr 2011). The history of D&T is dotted with changes to its subject content and influenced by the emergence of new technologies. Recently, the suite of D&T subjects in Ireland has undergone significant changes. These changes mark “a shift from the traditional focus of the subjects, aimed at developing craft skills and technical competence, to one that focuses on the development of transferrable knowledge, skills and attitudes” (McGarr 2011, p. 1). This shift also mirrors an international move “from the transmission of facts or the demonstration of skills towards the development of active, autonomous learners” (Dow 2006, p. 309). Such changes attempt to “encourage the active involvement of pupils in authentic and meaningful learning experiences” (Dow 2006, p. 307) with the integration of more collaborative practices. In this context D&T is well placed in the curriculum to begin to build and establish a community of learners.

## **3. COMMUNITY OF INQUIRY**

While D&T creates the settings for a community of learners, a community itself will not be meaningful unless teachers and pupils actually communicate with each other. Hence, the implementation of a theoretical framework that supports communication is of critical importance, as the most common pitfall in ICT-supported learning is taking for granted that communication will automatically take place just because an environment makes it technologically possible (Kreijns, Kirschner & Jochems 2003).

The Community of Inquiry (CoI) model (Garrison, Anderson & Archer 2000), represents a process of creating a deep and meaningful learning experience through social, cognitive and teaching presence. Social presence is “the ability of participants to [...] communicate purposefully in a trusting environment and develop interpersonal relationships by way of projecting their individual personalities” (Garrison, 2009, p. 352). Cognitive presence is “the extent to which the participants [...] are able to construct meaning through sustained communication”, (Garrison et al. 2000, p. 11). Teaching presence is “the design, facilitation, and direction of cognitive and social processes for the purpose of realising personally meaningful and educationally worthwhile

learning outcomes”, (Anderson, Rourke, Garrison & Archer 2001, p. 5). Therefore, the processes social, cognitive and teaching presence begins to inform the conditions for supporting communication between teachers and learners in second level education.

Garrison et al. (2000) first developed the CoI to investigate how the features of text-based language used in technology-mediated communication (TMC) might promote critical thinking and reflection. TMC is the hallmark of ICT-supported learning as it allows teachers and learners to structure dialogue much like how educational transactions develop within traditional classrooms (Garrison & Shale 1990). The ability to structure communication much like a traditional classroom is critical, as the integration of ICT in the classroom should be considered as a pedagogical tool or resource for teaching and learning and not a repository of data and information. Hence, the emphasis should be on how the integration of ICT within the classroom can support communication in the educational transaction if ICT is to enhance practice through individualised pace and feedback, collaborative learning and project-based learning. In the context of D&T this would include supporting communication with the use of scaffolded interactions where the act of design becomes the focus of conversation with the interactions being seen as a tool to develop a mutually appropriated concept. It is becoming increasingly clear that there is a synergy between the practice of D&T and the CoI processes, where the integration of the both, creates the conditions for supporting communication between teachers and learners in second level education.

If we consider using the CoI model for the integration of ICT within D&T education teaching presence, (i.e. the design, facilitation, and direction of social and cognitive processes), will have a significant influence on the teaching and learning experiences. Moreover, if the design, facilitation and direction of social and cognitive processes are to play such a key role in teaching and learning, then it makes sense to first look at the intersection between social and cognitive presence (i.e. supporting discourse). Here, teachers and learners move beyond the simple transmission of information to a more reflective interchange of thoughts, feelings and ideas (Redmond & Lock 2006). As was originally described by Foucault (in Weedon 1987, p. 108) discourse is more than just another form of communicating, thinking, working or producing meaning, discourse is a form of constituting knowledge, together with social practices, forms of subjectivity and power that exist in knowledge and the relation between them. Therefore, ICT should focus more on discourse and supporting discourse, rather than communication. Pfister and Mühlfordt (2002) offer empirical results which confirms the hypothesis of this research that supporting discourse leads to meaningful and educationally worthwhile learning. According to Pfister and Mühlfordt (2002) supporting discourse involves the use of learning protocols to increase the structure and efficiency of teaching and learning. This approach provides a support for discourse where teachers and pupils explicitly identify (code) the reference of their contribution, as well as the type of contribution. However, the real contributions learning protocols can make to teaching and learning are yet to be fully exploited within the classrooms of formal second level education. Hence, it was the aim of this research to conduct an exploratory study which investigated the role of learning protocols for supporting discourse using TMC within design-based activity in second level education.

#### **4. METHOD**

To capture the authenticity of the real world of teaching and learning a design experiments approach was identified as being an appropriate strategy (Brown 1992). Though Cohen et al. (2011) acknowledge that a design experiments approach does not conform to the requirements of a conventional experiment it involves a deliberate and planned intervention, much like a conventional experiment. Brown (1992) suggests that design studies engineer innovative educational environments and simultaneously conduct experimental studies of those innovations. Accordingly, the data collected facilitates the generation of ‘thick descriptions’ (Ceertz 1973), particularly of social processes, cognitive functions, and behaviours in tandem with measuring perceptions in order to understand the dynamics of TMC. A mixed methods approach was chosen for this study as the nature of the analysis would need to focus on qualitative and quantitative data. This included transcript analysis, pupil focus groups, teacher interviews, and surveys.

Based set criteria, 7 pre-service teachers (6 Male, 1 Female) were suitable for participation in this study. The pre-service teachers ranged from 20 – 27 years with a mean age of 22.29 and standard deviation of 2.29 years. In collaboration with the pre-service teachers, their co-operating teachers and their associated schools, the 6

week research intervention was integrated into 7 classrooms. The participating pupils in this study (n = 104) included 96 male and 8 female pupils. Although the female participants only make up 7.6% of the research sample, this is representative of the gender imbalance in D&T education in Ireland (DES 2007, p.4). The pupils varied in age from 15 – 18 with a mean average of 16.35 and a standard deviation of 0.77, and there was a mean average of 14.86 pupils in each classroom.

## 5. APPROACH

The EPI Model (Figure 1) was developed as a conceptual framework for supporting discourse (O’Connor, Seery and Canty 2016; O’Connor, Seery and Canty 2018), which provides diagnostic and formative evidence about the quality of pupil learning and efficacy of teacher pedagogy by developing the following elements and processes: the design of the learning environment, the delivery of the educational transaction, the experiential, procedural, and individual domains of teaching and learning.

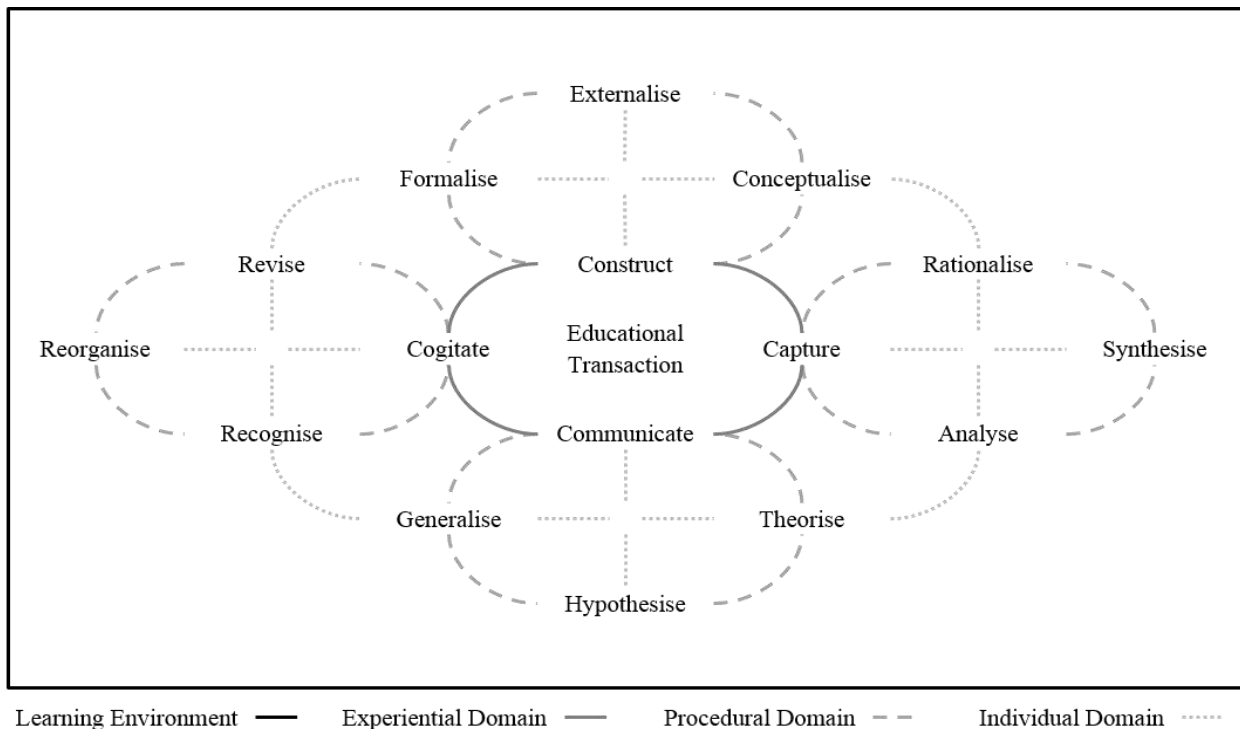


Figure 1 The EPI Model

In an effort to document evidence-based progress during the educational transaction and practically integrate the proposed EPI Model as a pedagogical approach, teachers and pupils were required to use a virtual learning environment (VLE) in conjunction with mobile technologies (e.g., smartphones, tablets) and stationary computers, to post matters associated with their process of learning and the product of their learning by: constructing theoretical knowledge and practical skills, capturing the learning process and evidence of their learning, communicating a/synchronously with group members, and cogitating on their learning process in both collaborative and individual contexts. The structure of posts added to the VLE were defined by each pupil to reflect the experience of their design process and represent the significance of their individual and collaborative approaches to forming solutions and showing evidence of learning. The nature of the data uploaded to the VLE and the modes of representation used were at the discretion of the pupils and facilitated by the file sharing capacity of the VLE. In other words pupils could attach various text, image, audio or video files and even share links.

As teachers base their intervention strategies and decisions on evidence (what pupils do, say, make or write), rather than inference (what pupils know, understand, think or feel), the capacity to identify pupils’ current and targeted progressions is fundamental as to when a person should or shouldn’t intervene in the process of pupils learning. However, to do so properly can prove difficult even for the most experienced teacher. For this to work

both in theory and practice, for teachers and pupils alike to base their intervention strategies and decisions on evidence, learning protocols based on a shared language of understanding have to first be established in order to support discourse. Hence, this research proposes that the protocols of the Procedural Domain can be used to 'self-code' the posts and comments teachers and pupils add to the VLE. A unique feature of most VLE's is the hash-tagging system which teachers and pupils have the option of integrating during the management of their posts and comments. While uploading their files to the VLE pupils have the option to create a tag or link between specific pieces of data and the learning protocols of the Procedural Domain. The # symbol, called a hashtag, was used by both teachers and pupils to self-code their individual and collaborative evidence posted as part of the educational transaction. Any one of the learning protocols could be assigned to a post or comment added to the VLE by a teacher or pupil using a hashtag, e.g., #conceptualise. However, it was not mandatory to hashtag as this may cause pupils to tag work for the sake of doing so. This required each pupil to reflect on the data being uploaded and to communicate it in terms of how it related to their own development within the educational transaction. This provides an insight into the perception of how pupils conceive and develop their thoughts, feelings, and ideas about the process and product of their learning. It should be noted that the learning protocols were open to interpretation by teachers and pupils and designed to be used to guide learning and not followed as a chronological set of procedures.

## 6. FINDINGS

Though all pupils (n = 104) in the 7 participating schools volunteered to take part within the study and had initially signed-up and created their Edmodo profiles, approximately 84% of pupils (n = 87) actively took part in the research intervention (i.e., working iteratively on the VLE, tagging posts and comments, collaborating with others and uploading subsequent data files (evidence) to complete the learning task). The remaining pupils (n = 17) engaged within the classroom activity as normal practice.

### 6.1. *The Frequency of Coding Interactions*

A total of 3866 codes were assigned to all 794 interactions recorded by S\_01 – S\_07, which means that on average, each interaction was assigned 4.87 codes (SD = 2.69). The total codes assigned per school ranges from S\_01 (n = 1112) to S\_07 (n = 196), which coincides with the interactions recorded by S\_01 (n = 237) to S\_07 (n = 32), and the weeks S\_01 (n = 6) to S\_07 (n = 4) participated in the research intervention. Social presence received the most amount of codes (n = 1202), which is approximately 31% of codes assigned to S\_01 – S\_07. The distribution of social presence when comparing each of the seven individual schools, indicates that social presence ranged from 22% of activity within S\_03 to 42% in S\_06. In addition, social presence was the highest coded element within S\_01, S\_04, and S\_06. However, the second most frequently coded element; learning protocols (n = 1100), which accounts for 28% of the codes, was the highest within S\_02, S\_03, S\_05, and S\_07. Contra to social presence, this ranged from 35% of activity in S\_03 to 20% in S\_06. Cognitive presence was assigned 26% of codes (n = 990), and was found to be the third most coded element in all schools, exclusive of S\_03. Akin to learning protocols, this ranged from 30% of activity in S\_03 to 20% in S\_06. This may suggest a possible link between learning protocols and cognitive presence, or this may just be indicative of their similar nature of categorising pupil activity. Finally, the remaining 15% of the codes (n = 574) were assigned to teaching presence. This was the least frequently coded element in all participating schools. Teaching presence ranged from a minimum of 12% of activity in S\_01 to a maximum 24% in S\_07.

In light of the perceived relationship between learning protocols and cognitive presence as indicated by the frequency of coding interactions, the research was then led to consider the display trend of the codes assigned per school. For example, as is shown in Figure 2 the trend of codes assigned by element for School 01 (S\_01) to learning protocols and cognitive presence followed a near identical path over time.

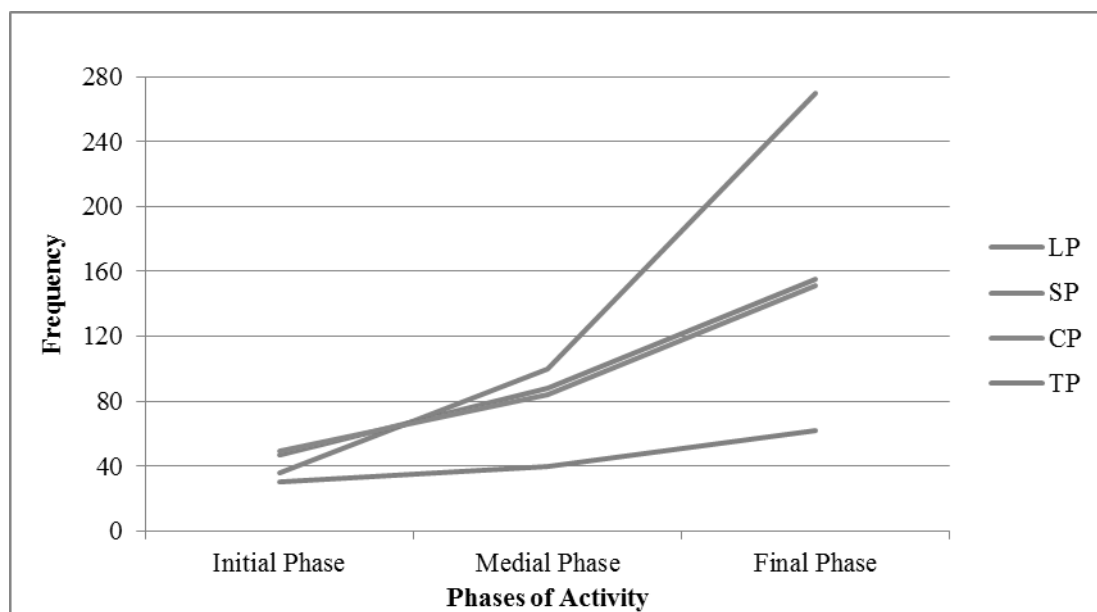


Figure 3 Display Trend of CoI and EPI Codes Assigned by Element (S\_01)

In light of this display trend, a correlational analysis was conducted between the CoI and EPI codes. The results of this correlational analysis, which are presented in Table 4, clearly indicate that there is a significant positive correlation between the codes assigned to learning protocols and cognitive presence.

Table 4 Correlation Matrix of CoI and EPI Codes

		<i>LP</i>	<i>SP</i>	<i>CP</i>	<i>TP</i>
<b>Learning</b>	Pearson Correlation		-.251**	.829**	-.001
<b>Protocols</b>	Sig. (2-tailed)		.000	.000	.975
	<i>N</i>		794	794	794
<b>Social</b>	Pearson Correlation			-.289**	.419**
<b>Presence</b>	Sig. (2-tailed)			.000	.000
	<i>N</i>			794	794
<b>Cognitive</b>	Pearson Correlation				-.075*
<b>Presence</b>	Sig. (2-tailed)				.035
	<i>N</i>				794
<b>Teaching</b>	Pearson Correlation				
<b>Presence</b>	Sig. (2-tailed)				
	<i>N</i>				

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

## 7. DISCUSSION

As teaching presence is the design, facilitation, and direction of social and cognitive processes for realising personally meaningful and educationally worthwhile learning outcomes, this research argues that discourse must ensue around both learning processes and outcomes to inform the quality of learning and efficacy of teaching. This study implemented the use of learning protocols (i.e., hashtags) to translate the EPI Model into a pedagogical and technological approach to help teachers and pupils articulate a common language of progression around the intended learning processes. Accordingly, this research shows that by creating a shared language of understanding the relationship between the frequency of teachers and pupils' use of these protocols, is evidence of an iterative and interactive process of learning in second level education. As presented

in the following extract taken from Teacher 01 (post-study), this was possible because the use of protocols allowed the reader to see and understand the process of learning, and in turn informed a person's capacity to identify both current and targeted progressions and whether or not they should or should not intervene within their process of learning:

*... when I can see what they hashtag, I can see what the pupils are thinking, so if its #conceptualise maybe they are looking to show what their ideas are, it gives teachers and whoever else is looking at it an idea of what the pupil or the other person's actually thinking and how they're actually doing it, (T\_01).*

In comparing the coding trends, a clear sense of hierarchical progression within the learning protocols was identified which further enabled participants to evidence their thinking in terms of progression. However, the classification of this hierarchy reveals similar issues which concern the CoI, i.e., learners are not reaching higher phases of critical thinking and reflection (Garrison et al. 2000; Garrison & Arbaugh 2007; Garrison & Cleveland-Innes 2005; Garrison & Vaughan 2008). Those studies claimed that the apparent inability to move to the higher phases was very likely associated with teaching presence. However, the results of the transcript analysis show that in schools where teachers recorded high percentages of learning protocols, pupils showed a greater capacity to move beyond exploration into the integration and resolution of cognitive presence. These findings are important as they show that effective use of the learning protocols along with engaged teachers and supported discussions have been found to be the most consistent predictors of the development of cognitive presence. Hence, the EPI Model can be used to support the design, facilitation, and direction of social and cognitive processes.

## 8. CONCLUSION

In addition to creating a shared language of understanding between participants, the nature of discourse and the language of that discourse was shown to be cognitive. In light of the perceived relation between learning protocols and cognitive presence this study was led to consider the codes assigned per school. The findings indicated that learning protocols and cognitive presence followed a near identical path in all of the schools during the activity. Subsequently, a correlational analysis was conducted between the codes assigned by the researcher to learning protocols and to social, cognitive and teaching presence. The results of this analysis indicated a significant positive correlation between learning protocols and cognitive presence, showing that supporting discourse and the language of that discourse is cognitive, e.g., interactions coded in the resolution category of cognitive presence were frequently coded in the cogitation category of the Experiential Domain. Hence, this research indicates that, in conjunction with the EPI Model, the use of learning protocols is a relevant approach to supporting cognitive presence. This research further indicates that the process of supporting discourse is meta-cognitive. Although the spatial and temporal independencies gave pupils more time to critically think and reflect on their interactions with others, by working iteratively, using the EPI Model to assign learning protocols to posts and comments, working with others, and uploading subsequent data files as evidence, encouraged pupils to critically think and reflect on their interactions with themselves. This included having to share the evidence of your learning within the public sphere and having to assign a learning protocol that was appropriate to the evidence shared. For example, as shown in the following extract as taken from Pupil 77 (focus-group), the pupils identified two common factors that promoted meta-cognitive awareness:

*... with the hashtags, we were analysing our own work, we were sharing it with everyone else, we were communicating our ideas with everyone else, but we were also communicating with ourselves, (P\_77).*

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# Innovating an Initial Professional Education of Technology Teachers (IPETT) Programme

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The decreasing number of students who meets the entrance requirements for the four-year undergraduate degree in technology education as part of the IPETT programme is a serious concern. However, we have implemented innovative and imaginative ways to attempt to turn this trend around. The purpose of this research is to explore some of the innovative and imaginative ways to address these concerns so that we can build human capacity. The participants were the enrolled students for the above-mentioned programme in 2016 (Cohort 1) and 2017 (Cohort 1 and Cohort 2). The research questions were: What innovative curriculum options and entrance requirements could be implemented? What innovative changes could be made to lecturers' pedagogy to meet the needs and challenges of students who enrolled under the more flexible curriculum options? How do the expectations, experiences and performances of the first cohort's first-year students who did or did not have Engineering Graphics and Design (EGD) as a subject in Grade 12 compare to those of the second cohort's first-year students? and How do the initial expectations, experiences and performances of the first cohort's students in their first year who did or did not have EGD as a subject in Grade 12 compare with those in their second year? A mixed-method methodology was utilised including various open and semi-structured questionnaires and students' academic performance at the end of each semester. A comparison between Cohort 1 and Cohort 2 was done and simultaneously a longitudinal study with Cohort 1 over a period of two years. The findings revealed that implementing more flexible curriculum options and utilising innovative pedagogical practices could be ways to address the concerns. The findings contribute toward the body of knowledge in the sense that EGD at secondary level should not necessarily be a prerequisite for admitting prospective technology student teachers to an IPETT programme.

*Key words: Flexible curriculum options, Innovative pedagogical practices, Challenges, Attitude.*

## 1. INTRODUCTION

The Department of Education has launched a Technical High Schools Turnaround Strategy in 2013. The objectives of this strategy was to expand the opportunities available for technical education, to increase the enrolment of technical students, to increase the human resource capacity for the offering of technical subjects and to involve Higher Education Institutions and FET colleges to support technical schools in achieving these outcomes. In South Africa the last three school years of technology education is referred to as technical education.

This university plays an important part in the education of technology teachers but despite technology-related subjects being regarded as scarce subjects extremely low numbers of students opt for these subjects over the past few years. The rigid entrance requirements for the four-year undergraduate degree in technology education as part of the IPETT programme could be one of the impediments. We had to find innovative and imaginative ways to turn this trend of low enrolment numbers around to be able to increase this specific human resource capacity.

The purpose of this research was to explore some of the innovative and imaginative ways to address these concerns so that we can build human capacity. The research questions were:

- (i) What innovative curriculum options and entrance requirements could be implemented?

What innovative changes could be made to lecturers' pedagogy to meet the needs and challenges of students who enrolled under the more flexible curriculum options?

How do the expectations, experiences and performances of the first cohort's first-year students who did or did not have Engineering Graphics and Design (EGD) as a subject in Grade 12 compare to those of the second cohort's first-year students?

How do the initial expectations, experiences and performances of the first cohort's students in their first year who did or did not have EGD as a subject in Grade 12 compare with those in their second year?

## **2. CONTEXT OF THE STUDY**

### ***2.1. Curriculum options and entrance requirements***

One of the qualifications for initial teacher education at this South African university is a BEd degree in Technology (Senior Phase and FET) with specialisation Engineering Graphics and Technology Education (EGTE), up to third-year level, and Civil Technology up to second-year level.

Having done EGD at Grade 12 level was a prerequisite for students to enrol for the programme in 2013, 2014 and 2015. However, student enrolment dropped from 17 to eight to zero respectively, therefore, we had to put the intake of new first-year technology students on hold for 2015. After intensive consultation with stakeholders, more flexible curriculum options for the 2016 intake were set whereby EGD as entrance requirement was dropped, and EGD on second-year level could be combined with Physical Sciences or Geography or Mathematics at third-year level. Students only had to comply with the entrance requirements for their specific majors in the Faculty of Science. This decision was supported by the fact that the academic discipline on which technology is based is manifested in more than one of the mentioned disciplines (Ankiewicz, 2015). According to Ankiewicz (2015) technology can be seen as a multi-discipline or a poly-discipline, of which components are spread over more than one discipline. The expectation was that the more flexible curriculum options would support the agenda to increase the human resource capacity for technical education.

### ***2.2. Pedagogical practices***

During 2016 the first-year students of Cohort 1 had one double period class per week which was facilitated by a lecturer and the focus was on the development of conceptual knowledge (knowing that). Due to the more flexible curriculum options and entrance requirements, the lecturers realised that they had to provide more intensive support to the students without EGD at secondary level. These students needed sessions focused on practical apprenticeship providing an interaction between an expert and a novice (Jakovljevic and Ankiewicz, 2015) to develop the novices' procedural knowledge (knowing how). A double period per week was set aside for practical apprenticeship (tutorial) which was facilitated by an expert. The expert guidance was given in a peer-based collaborative learning environment (Jakovljevic and Ankiewicz, 2015). The appointed expert, a qualified draughtsman with related work experience, is a practicing technology teacher at a nearby secondary school. An additional expert, a student in Technology Education on an Honours level, was appointed at the beginning of 2017 as a tutor assistant to provide individual attention during the tutorials and consultation times so that the second-year students from Cohort 1 and the first-year students from Cohort 2 could better cope with the learning content.

## **3. RESEARCH DESIGN**

A mixed-method approach was utilised whereby quantitative and qualitative data were collected (Creswell, 2003; Creswell, 2005). Students enrolled for Engineering Graphics and Technology Education (EGTE) in 2016 were considered as Cohort 1 and students who enrolled for EGTE in 2017 were considered as Cohort 2. A number was allocated to each student to ensure anonymity. The only person who could identify the specific participant was the researcher who was not involved in teaching the students. Ethical clearance for this study was granted as it adhered to all the required conditions set by the research ethics committee.

Biographical data related to the students' Grade 12 subjects were collected. Open and semi-structured questionnaires were completed at the beginning and the end of each semester. The focus of these questionnaires was on students' expectations and experiences of the various semester modules of EGD and the pedagogical practices. The challenges that students might experience would then lead to innovative changes to the lecturers' pedagogy and support systems (refer to research questions 2, 3, and 4). The students' academic performances at the end of each semester were captured and the overall final mark for the year were calculated. A comparison between Cohort 1 and Cohort 2 was done and simultaneously a longitudinal study was done with Cohort 1 over a period of two consecutive years.

## 4. RESULTS

### 4.1. Biographical data and academic performances at tertiary level

The biographical data related to the students' required Grade 12 subjects and their overall final mark for EGTE, as indication of their academic performances, are indicated in Tables 1 and 2. The learning content for EGTE 1 included basic drawing techniques, and geometrical and orthographic concepts, while mechanical and civil drawings formed part of EGTE 2.

Table 1. Quantitative data of Cohort 1

Number of student	Gender	School subjects					EGTE 1		EGTE 2	
		EGD	Maths	Maths Literacy	Physical Sciences	Geography	2016 Final Mark (%)	2017 Final Mark (%)		
1	Female		Yes		Yes	Yes	59		57	
2	Male	Yes	Yes		Yes		62		67	
3	Female		Yes		Yes	Yes	57		54	
4	Female		Yes		Yes	Yes	53		62	
5	Male			Yes			63		70	
6	Male			Yes		Yes	75		77	
7	Female	Yes	Yes			Yes	79		73	
8	Male		Yes		Yes		51		46	
9	Male		Yes		Yes	Yes	60		58	
10	Male	Yes	Yes		Yes		68		58	
11	Male	Yes	Yes		Yes		84		78	
12	Male	Yes	Yes			Yes	78		60	
13	Male	Yes		Yes			69		65	

Table 2. Quantitative data of Cohort 2

Number of student	Gender	School subjects					EGTE 1	
		EGD	Maths	Maths Literacy	Physical Sciences	Geography	2017 Final Mark (%)	
21	Female		Yes		Yes	Yes	61	
22	Male		Yes		Yes	Yes	59	
23	Female		Yes		Yes	Yes	56	
24	Male		Yes		Yes	Yes	67	
25	Female		Yes		Yes	Yes	--	
26	Female	Yes		Yes			78	
27	Male	Yes	Yes				90	
28	Female		Yes		Yes	Yes	51	
29	Female		Yes		Yes		54	

Student 25 did not write the exam at the end of the second semester and had to be excluded from the quantitative analyses.

### 4.2. Comparison between the performances in EGTE 1 in 2016 of Cohort 1 students with or without EGD at secondary level

The data from the two groups were subjected to the Kolmogorov-Smirnov (D) test to see if the distribution differs significantly from the normal distribution. The values were as follows: EGDYes (6) = 0.193;  $p = 0.200$ ;

EGDNo (7) = 0.190;  $p = 0.200$ . Therefore, the test is non-significant ( $p > 0.05$ ) which suggests that the distribution of the population was not significantly different from a normal distribution. Hence, the data can be subjected to an independent means t-test as the two groups either took EGD at secondary level or they did not take it as a subject indicating an unpaired situation (Cohen, 1988). Table 3 represents the group statistics related to the performances of the students.

*Table 3. Group statistics related to the performances in EGTE 1 in 2016 for Cohort 1*

<i>EGD in Grade 12</i>	<i>Number of students</i>	<i>Mean score for EGTE 1</i>	<i>Standard deviation</i>	<i>Standard error mean</i>
Yes	6	73.33	8.29	3.38
No	7	59.71	7.89	2.98

An independent means t-test was conducted to compare the mean scores for the two groups. The significance level for Levene's test was 0.53 meaning the assumption of equal variances was not violated. There was a statistically significant difference in the mean score for students with EGD ( $M = 73.33$ ,  $SD = 8.29$ ) and students without EGD,  $M = 59.71$ ,  $SD = 7.89$ ;  $t(11) = 3.03$ ,  $p = 0.01$  (two-tailed). Therefore, the students who did have EGD as a subject in Grade 12 scored statistically significant higher than the students who did not have EGD (73.33% and 59.71% respectively, see Table 3).

In addition, the calculated effect size indicated an Eta squared value of 0.455 (Pallant, 2007) which can be valued as a large effect (Cohen, 1988) and Cohen's  $d$  (1.68) with  $r = 0.64$  (medium to large effect) and hence the effect of having done EGD as a subject in Grade 12 is important. A website calculator (<https://www.uccs.edu/~ibecker/>) was used to calculate Cohen's  $d$  and the related effect size.

#### ***4.3. Comparison between the performances in EGTE 1 in 2017 of Cohort 2 students with or without EGD at secondary level***

Seeing that the measures are numeric, the data has a normal distribution, the whole populations was included in the study and the two groups are independent, the data can be subjected to an independent means t-test. Table 4 represents the group statistics related to the performances of the students.

*Table 4. Group statistics related to the performances in EGTE 1 in 2017 for Cohort 2*

<i>EGD in Grade 12</i>	<i>Number of students</i>	<i>Mean score For EGTE 1</i>	<i>Standard deviation</i>	<i>Standard error mean</i>
Yes	2	84.00	8.49	6.00
No	6	58.00	5.66	2.31

The significance level for Levene's test was 0.50 meaning that the assumption of equal variances was not violated. There was a statistically significant difference in the mean score for students with EGD ( $M = 84.00$ ,  $SD = 8.49$ ) and students without EGD,  $M = 58.00$ ,  $SD = 5.66$ ;  $t(6) = 5.12$ ,  $p = 0.00$  (two-tailed). Therefore, the students who did have EGD as subject at Grade 12 scored statistically significant higher than those who did not have EGD (84.00% and 58.00% respectively, see Table 4).

The calculated effect size indicated an Eta squared value of 0.814 (Pallant, 2007) which can be considered as a large effect (Cohen, 1988) and Cohens'  $d$  (3.61) with  $r = 0.88$  (large effect) and therefore the effect having done EGD as a subject in Grade 12 is important.

#### ***4.4. Comparison between the performances in EGTE 2 in 2017 of Cohort 1 students with or without EGD at secondary level***

Seeing that the measures are numeric, the data has a normal distribution, the whole populations was included in the study and the two groups are independent, the data can be subjected to an independent means t-test. Table 5 represents the group statistics related to the performances of the students.

*Table 5. Group statistics related to the performances in EGTE 2 in 2017 for Cohort 1*

<i>EGD in Grade 12</i>	<i>Number of students</i>	<i>Mean score For EGTE 1</i>	<i>Standard deviation</i>	<i>Standard error mean</i>
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Yes	6	66.83	7.63	3.11
No	7	60.43	10.36	3.92

The significance level for Levene's test was 0.48 meaning that the assumption of equal variances was not violated. There was no statistically significant difference in the mean score for students with EGD (M = 66.83, SD = 7.63) and students without EGD, M = 60.43, SD = 10.36;  $t(11) = 1.25$ ,  $p = 0.24$  (two-tailed). Therefore, by the end of their second year it seems that the performances of students who did have EGD in Grade 12 and those without EGD in Grade 12 are similar.

For Cohort 1 five of the six students who did have EGD at secondary level had a final mark for EGTE 1 of 67% or more in 2016 whereas not one of the students without EGD but with Mathematics and Physical Sciences at secondary level could achieve 67% or more. Three of the six students who did have EGD at secondary level had a final mark for EGTE 2 of 67% or more in 2017 whereas not one of the students without EGD but with Mathematics and Physical Sciences at secondary level could achieve 67% or more.

#### 4.5. Qualitative data related to a comparison of Cohort 1 and Cohort 2

Due to the alternative entrance requirements whereby students from both cohorts no longer needed to have EGD at Grade 12 level, it was decided to compare the expectations and experiences of those with and those without EGD at Grade 12 level, of the two cohorts (see Table 6). The two Cohorts were compared because students from Cohort 1 only had access to a tutor while students from Cohort 2 had access to the support of a tutor and a tutor assistant. The data were collected by means of open-ended questionnaires which were completed in class. The 'EGD' in brackets refer to students who have had EGD as a subject in Grade 12 and the 'No EGD' in brackets are referring to students who did not.

Table 6. Examples of students' feedback during their first year of study

	Variable	Students from Cohort 1	Students from Cohort 2
Beginning of the first semester	Initial expectations of EGTE as a major	'A good challenge to learn new skills and to improve on previous skills that I have learned previously in high school.' (EGD)	'I expect engineering graphics and technology to be a challenging subject.' (EGD)
		'... and to get a huge support as possible since I have not done it at school.' (No EGD)	'As I do not have any background on the module I feel as if it will be a bit of a challenge to understand and catch up, or rather keep in pace with the rest of the students.' (No EGD)
	Feelings about taking EGTE as a major	'I feel positive and feel that I will master skills within the major to become a skilled educator.' (EGD)	'I also feel a bit nervous because it was my worst scoring subject in Grade 12.' (EGD)
		'Taking EGTE as a major makes me feel scared because I never did it at school.' (No EGD)	'I feel excited it will be new for me but I enjoy learning about how things operate so I think I will have a very fulfilling time in the EGTE subject.' (No EGD)
End of the first semester	Experiences of EGTE 1A	'It was hard to remember vividly the technical drawings although I did the subject in high school.' (EGD)	'To me this semester we only did revision of what we did in Grade 12. I did not have any fear or anxiety during the semester.' (EGD)
		'Truly speaking and from the bottom of my heart first semester module, EGTE 1A was hell of a module.' (No EGD)	'I thought it was going to be a breeze at first but it was a storm. My first theory classes were not a problem, I was able to understand them but my practical classes were hard as the lessons were moving very fast and I had no basics. At first I didn't even know how to use my drawing board and T-square but now I'm getting it. (No EGD)
			'I feel disappointed with the fact that the subject is not challenging me.' (EGD)

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<i>End of the second semester</i>	<i>Experiences of EGTE 1B</i>	<i>'I expected EGTE 1B to give me clarity regarding drawing principles which was done to my satisfaction. My drawings improved gradually and I could relate what we do in class to the outside world.'</i> (EGD)	<i>'I should not have taken it as I think I have ruined my life and future. It was too hard for me and I do not think I would recommend it to anyone with no prior experience.'</i> (No EGD)
		<i>'I managed to obtain an excellent mark in EGTE 1B. This was the initial plan before I started the module and all my expectations for the module were successfully achieved.'</i> (No EGD)	

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From Table 6 it seems that there are no major differences regarding the students' (four groups) feedback on the questionnaire, except for the last two remarks by students from Cohort 2. The student who stated that EGTE 1B was not challenging enough did EGD, Civil Technology and Mechanical Technology in Grade 12 and obtained distinctions for two of these subjects. In spite of having access to a tutor and a tutor assistant, the student from Cohort 2 whose 'life and future were ruined' did not qualify to write the exam.

#### 4.6. Qualitative data related to Cohort 1

The qualitative data were collected by means of various questionnaires over a time span of two consecutive years. The quotes are representative of the dominant feedback by the students. The data from the students who had EGD and those who did not have EGD in Grade 12 are indicated separately in Table 7 so that the feedback by the various groups on the open-ended questionnaire could be compared.

Table 7. Examples of Cohort 1 students' feedback during their first year of study

	Variable	Students with EGD in Grade 12	Students without EGD in Grade 12
<i>Beginning of the first semester - EGTE 1A</i>	<i>Initial expectations of EGTE as a major</i>	<i>'I am expecting to be the best student and to excel in this module.'</i>	<i>'I expect to see myself succeeding in this module no matter how tough it might be.'</i>
	<i>Feelings about taking EGTE as a major</i>	<i>'I actually feel great with EGTE because I loved EGD in Grade 10 to Grade 12.'</i>	<i>'I feel very good about it and I am looking forward to it.'</i>
<i>End of the first semester - EGTE 1A</i>	<i>Experiences of EGTE 1A</i>	<i>'One of the topics that drained my energy was geometrical construction, so I had to work very hard when the exam was around the corner.'</i>	<i>'Truly speaking and from the bottom of my heart first semester module, EGTE 1A was hell of a module. The thought of quitting was always on my mind.'</i>
<i>End of the second semester - EGTE 1B</i>	<i>Satisfaction of expectations</i>	<i>'Yes, I wanted to be able to analyse and draw neat and clear drawings using equipment and to be able to draw clear freehand drawings. My skills improved.'</i>	<i>'Yes, I expected to learn more about how technology satisfy or make people's lives easier of which I learnt in 2016 and now I know how technology contribute to the world. I also expected to learn how to draw and I have learnt more about drawings. I learnt how to design.'</i>

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Students from both groups, those with EGD and those without EGD, experienced the first semester module as challenging but by the end of the second semester students indicated the module satisfied their expectations (refer Table 7).

The data for Table 8 were collected by means of an open-ended questionnaire.

Table 8. Examples of Cohort 1 students' feedback at the beginning of the first semester of their second year of study

Variable	Students with EGD in Grade 12	Students without EGD in Grade 12
Expectations of EGTE 2A	'My overall expectation/s for my experience in the course is that of an enjoyable and educational outcomes that will assist me in my overall understanding of this module and the various aspects linked to it.'	'I also expect this module to equip me with the necessary skills I will need for my future practice as a teacher. This means that I will be also accountable for my schoolwork.'
	'I also expect that we should be given as many activities for practice.'	'In EGTE 2A I expect to know more about mechanical drawings. How mechanical objects operate. And I also expect to know how we relate those drawings to the careers of our future learners as student educators.'

It follows from Table 8 that both groups had a positive attitude towards EGTE 2A and they indicated their expectations regarding pedagogical principles.

At the end of the first semester of their second year students from Cohort 1 received a semi-structured questionnaire. Questions regarding own personal experiences and their experiences of the teaching in the module were included. Students from both groups gave similar feedback (refer to Table 9).

Table 9. Examples of Cohort 1 students' feedback at the end of the first semester of their second year of study

Variable	Students with EGD in Grade 12	Students without EGD in Grade 12
Own personal experiences of EGTE 2A: Anxiety/Fear	'With every new challenge or concept my <b>fears grow greater</b> as the level of complexity keeps on increasing'	' <b>Time for completing some tasks</b> such as semester tests is very limited leading to incomplete or wrong answers due to stress and <b>anxiety</b> .'
Feelings	'I like this module, I <b>feel inspired</b> every day I attend it with an encouragement at the back of my mind I know that I will make it ...'	'The <b>experience</b> with the tutors, assistant, peers and the lecturer has been <b>good</b> because I learn a lot from each one of them.'
Time	'... since there is less time for completing the tests and exams which are sometime really challenging. Time allocation for the tests is <b>so little</b> ...'	'Time for completing some tasks such as semester tests is <b>very limited</b> ...'
Something new	'I am <b>still trying to find my way</b> around it.'	'... some of us never did EGD in high school, we <b>become really confused</b> when we encounter something new in the exam, something we never seen before. You find that you are thinking but nothing is adding up because you do not have that drawing knowledge.'
Dealing with demands	'Had it not been for the weekly assignments <b>chances are that I would not make it</b> .' 'The assignments is where we supposed to get marks from, but I feel as if you <b>too strictly in marking</b> .'	'... the portfolio for the practical has unnecessary fields that are required that <b>cannot help us with anything but to take our time</b> (e.g. the case of the whatever we are going to make, the disadvantages and the advantages before we do the project and others).'

Experiences of the teaching in EGD 2A: Lecturer	'The lecturer has taught the content at a reasonable pace and has always offered his assistance when required and has also used and explained concepts in such a way that it promotes understanding.'	'The lecturer has made my learning experience fruitful by <b>explaining to us</b> the requirements of what needs to be done, and also offers <b>assistance</b> with regards to what has been covered in the classroom'.
Tutor	'I appreciate his concern when content is not clearly understood and he then makes a concerted <b>effort to assist</b> us in understanding and retaining this information.'	'The tutor has been good in terms of simplifying concepts and <b>offering assistance</b> with any problems we may encounter in the tutorials. The experience with the tutor has been excellent.'
Tutor assistant	'The assistant tutor does help but I feel like she expect a lot from us when she sees others doing well. I feel like her presence makes the classroom a bit tense.'	'Offers great help and assistance at all times. The assistant also makes sure that she makes times for consultations and also <b>helps in clarifying concepts</b> which are challenging.'
Peers	'Those who do well in class put me under <b>pressure</b> as it is depressing to see them getting good marks while some of us are struggling to qualify. But we do <b>get along well</b> .'	'My peers offer great assistance and support with regards to the content covered in class and in tutorials. We often prepare for assessments together and <b>helping each other</b> in academic related issues.'

From Table 9 it follows that students from both groups, students with EGD and those without EGD in Grade 12, experienced some sort of anxiety, have positive feelings, are concerned about the time allocation, found it hard to deal with something new, and indicated that the demands are challenging. Students from both groups indicated that they appreciated the assistance from the lecturer, tutor, tutor assistant and peers. However, students who had EGD in Grade 12 indicated that the tutor assistant 'makes the classroom a bit tense' and that they experience 'pressure' among their peers.

The next open-ended questionnaire was administered at the beginning of the second semester of the second year of study dealt with the expectations for the second semester module and the researchers wanted to know what would assist them to better cope with the expected challenges (refer to Table 10).

Table 10. Examples of Cohort 1 students' feedback at the beginning of the second semester of their second year of study

Variable	Students with EGD in Grade 12	Students without EGD in Grade 12
Expectations of EGTE 2B	'Lastly, is to ensure that I <b>complete this module with flying colours</b> or ace the module by being given all the aids of assistance.'	'I want this semester to be interesting and enclosed with <b>hard work and perseverance</b> from both the students and the lecture.'
	'As far as the course is concerned, I do not anticipate any challenges at present, with the pace of the course as I am aware that the lecturers see to it that there is a <b>reasonable pace</b> from one concept to another.'	'As long as <b>we work together</b> as the class together with the lecturer, we will defeat failure and confusion.'
	'I am hoping <b>more time</b> will be given to longer topics to enable us to fully understand what civil drawings are and how to go about interpreting them'. 'However, a challenge that I always face with civil drawings is time-coverage ...'	
What would assist you to better cope with the expected challenges?	'I think it would be better if the tutor and a tutor assistant have their own <b>consultation time</b> besides the tutorials on Wednesday, so that if an individual does not understand a certain topic can consult.'	'I would like the lecturer and the tutors to be patient with us and give us <b>enough time</b> to understand what is expected from us.'



It follows from Table 10 that students from both groups, students with EGD and those without EGD in Grade 12, seemed to have a positive attitude and some of them referred to the pedagogical practices of following a reasonable pace and cooperation in the classes. Regarding what would assist them to better cope with the expected challenges some students also mentioned that they would like to get possible questions that will appear in tests and exams; they regard weekly assignments of the utmost importance; and that they would like to receive homework for extra practice.

During the last class of the year the students had to complete a questionnaire which included open and semi-structured questions. The variables of the semi-structured questions are indicated in the aspect column (see Table 11).

Table 11. Examples of Cohort 1 students' feedback at the end of the second semester of their second year of study

Variable	Students with EGD in Grade 12	Students without EGD in Grade 12
Experiences of EGTE 2 compared to EGTE 1:		
<b>Subject/ content knowledge and skills</b>	<p>'As expected, the content in the second year course had been or has been <b>more challenging</b> than those in first year ...'</p> <p>'The second year modules were <b>more abstract</b> than the first year modules ...'</p> <p>'... they had been challenging in the sense of <b>time management</b> ...'</p>	<p>'When compared to my first year modules, my second year modules were <b>more demanding</b> and they required consistency.'</p> <p>'The second year content is far different and <b>much harder</b> compared to the first year. I think it is because in the first year the subject was new to me but now even though it is hard I am able to follow much easier.'</p>
<b>Teaching and learning:</b> Lectures	'I could not understand some of the topics especially in civil drawings, other than that I think the lecturers (and the tutors) were able to explain and teach everything in detail for us as students to understand.'	'The lectures (and tutorials) were of a great use because they make sure we understand the content.'
Tutorials	'I could not understand some of the topics especially in civil drawings, other than that I think (the lecturers) and the tutors were able to explain and teach everything in detail for us as students to understand.'	'Even on tutorials the addition of the tutor assistant was of a great use because they are now able to engage with one of us individually.'
Personal learning experiences	'During the course of the first-year modules my personal experiences vary from those in second-year. The main occurrence for this had been the content, personally the content taught in first year had been manageable and less challenging in that sense ...'	'Teaching and learning was very productive in lectures and in tutorials.'
Challenges	'... in the second-year the expectations had increased in terms of what had to be done.'	'The main challenge for me both the first and the second year modules was the time allocated for semester tests. This led to a few semester test to be submitted while incomplete.'
<b>Resources</b> Lecturers	'... in both second-year and first-year the lecturers (and tutors) had and have been of great support in terms of content understanding throughout these two years.'	'The lecturer, (tutors and classmates) provided enough support to advance my knowledge base.'
	'... in both second-year and first-year the lecturers	'... the activities they give us every week help us

<i>Tutor</i>	<i>(and tutors) had and have been of great support in terms of content understanding throughout these two years.'</i>	<i>practice and to possibly improve our marks EGTE 2B seemed to be a lot of work but with the help of ... and my tutors I managed to improve.'</i>
<i>Tutor assistant</i>	<i>'... in both second-year and first-year the lecturers (and tutors) had and have been of great support in terms of content understanding throughout these two years.'</i>	<i>'... both the tutor (and the tutor assistant) would give us assessments and it was a great strategy.'</i>
<i>Drawing equipment</i>	<i>'I now can say that I am finally exposed to a lot of drawing tools and equipment that we need to draw with. Comparing this with my high school EGD in KZN, I never knew a flexi curve nor use both set squares together when I had to draw without a T-square e.g. non-isometric lines.'</i>	<i>'In terms resources, I was adequately covered and there were no major problems experienced.'</i>

Although the students were asked to make suggestions that will help them to meet the challenges they had experienced in the programme over the past two years, the majority of them wrote about the overall challenges they had experienced without providing any suggestions (refer Table 11). However, a few of them did suggest that more time should be allocated to them to be able to finish their assignments during tests and the exam. One student wrote: “The issue of teaching theory in class should be eliminated and students should spent more time drawing since this is what they will be doing in the exam.”

## 5. CONCLUSION

By introducing more flexible curriculum options and dropping EGD as entrance requirement (refer to the first research question), 19 students could enrol for the program in 2016 of which 13 completed their second year successfully. Nine students enrolled for the programme in 2017 of which eight completed their first year successfully. Therefore, moving away from the rigid entrance requirements, inter alia, having done EGD at secondary level, to allow students with Grade 12 subjects from related disciplines (Ankiewicz, 2015) to follow a more flexible curriculum, increased the human resource capacity.

The implementation of tutorial sessions, the appointment of an expert in the field as a tutor, and appointing the tutor assistant testify the innovative changes made to the lecturers’ pedagogy (refer to the second research question). The collaborative learning environment (Jakovljevic and Ankiewicz, 2015) was invaluable for the students and much appreciated as mentioned in the feedback on various questionnaires.

Although the students from Cohort 1 and Cohort 2 who have done EGD in Grade 12 achieved statistically significant higher marks at the end of their first year than those who did not have EGD in Grade 12, the last group also completed their year successfully (refer to the third research question). Furthermore, the performance of students from Cohort 1 with and those without EGD in Grade 12 equalise by the end of their second year of study (refer to fourth research question). This might be a consequence of the innovative and imaginative pedagogical practices which were introduced in the learning environment contributing towards capacity development.

The qualitative data from the various questionnaires do not show important differences between the various groups of students (refer to the third and fourth research questions). The overall findings indicate that all students experienced challenges from time to time, had a positive attitude towards the modules, and appreciated the support they have received from the lecturers, the tutor, the tutor assistant as well as their peers. The biggest concern seemed to be the need for more time allocated to be able to finish their assignments in the tests and during the exam.

Finally, having done EGD as a subject in Grade 12 had a large effect on the final marks for EGTE 1 of students from Cohort 1 and Cohort 2. However, having done EGD at secondary level is not essential to pass at tertiary level as long as ample support is provided to meet the students’ needs and challenges. This might be of particular interest to the PATT fraternity.

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# Developing Technology Student Teachers' Volition through Curriculum-related Excursions

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Technology student teachers at a South African university have to opt for two academic majors, as a requirement for a four-year undergraduate degree in technology education. The curricula for the academic majors and the teaching methodology and practicum (PCK) modules should address cognitive, affective (volition) and behavioral aspects. However, a fourfold set of criteria was applied to the intended curricula of their academic majors, and it was found that specifically the volitional aspects of technology are largely not addressed (Ankiewicz, 2015). Subsequently, it was decided to introduce appropriate formal excursions to curriculum-related industries as a form of learning from practice to supplement the largely lacking volitional aspects in their curricula. By exposing the students to the design and make processes in the various industries they acquire mainly technological conceptual knowledge about and understanding of these processes which may improve their attitudes toward technology as concept appears to influence affect (Ankiewicz, 2016). Over a period of three years excursions were undertaken to industries such as Aerosud (material processing), Bosch (manipulative skills), the Lethabo Thermal Power Station (electrical systems), Sentech (electronic systems) and Nissan South Africa (mechanical technology, production lines). The purpose of the research was to determine the extent to which these formal excursions succeed in developing student teachers' attitudes towards technology. The research question that underpinned this research was: To what extent did the formal excursions succeed in the development of student teachers' attitudes towards technology? The participants comprised technology student teachers from two cohorts. A qualitative study was conducted by which data were collected through the observation of the students during the formal excursions, written reflections, and open-ended questionnaires that they completed afterwards. The data were analysed using the constant comparative method (Merriam, 1998). The main finding was that the formal excursions served as a means to compensate for the lacking volitional aspects in the curricula for the academic majors as well as the teaching methodology and practicum (PCK) modules.

*Key words: Teacher education, Volition, Excursions*

## 1. INTRODUCTION

### *1.1 Background to the study*

At the university concerned a four-year undergraduate degree in technology education is offered where student teachers enrol for two academic majors, namely Engineering Graphics and Technology Education (EGTE), up to third-year level, comprising six semester modules and Civil Technology up to second-year level, comprising four semester modules.

According to Ankiewicz (2018), the use of Mitcham's philosophical framework of technology is becoming increasingly prevalent in technology education. The framework consists of four modes of the manifestation of technology, namely: object, knowledge, activity and volition (Mitcham, 1994) and according to Ankiewicz (2013a), these are directives for technology classroom pedagogy as well as for technology teacher education (Ankiewicz, 2013b). Based on this framework Ankiewicz (2015) developed a fourfold set of criteria for curriculum development and evaluation. These were applied to the learning guides for each module of the academic majors. Part of the purpose of the learning guides is to serve as work schedules indicating the weekly distribution of themes and their related assessment criteria per semester. A shortcoming of the curriculum, as identified through the analysis of the mentioned learning guides showed that no volitional aspects were addressed (Ankiewicz, 2015).

## ***1.2 Attitudes***

The curricula for the academic majors as well as the teaching methodology and practicum (PCK) modules, within the undergraduate technology education programme, should address cognitive, affective (volition) and behavioral aspects. According to the traditional approach (Ankiewicz, 2016), an attitude towards a concept such as technology is based on a person's beliefs about it (cognitive component) and is associated with emotional reactions (affective component). The stimulation of these reactions results in decisions to engage in behavior (behavioural component), such as choosing to take a technology course. Context is an important determinant or predictive characteristic that influences students' attitudes. PATT studies indicated that students' concepts of technology are strongly related to their attitudes toward technology. Concept appears to influence affect and not the other way around. This result indicates that a clearer concept of technology among pupils will have a positive influence on their attitudes toward technology (Ankiewicz, 2016; Rohaan et al., 2010). On the other hand Svenningsson, Hultén and Hallström (2018) reported that both attitudes and interest can be seen as motivational variables. In the study involved, technology is the object of interest and it can be seen as a motivational factor for becoming engaged with the subject. According to Ankiewicz (2016), it seems that the traditional approach to attitudes may resemble Mitcham's framework in which technological knowledge (epistemology) and volition are prerequisites for technological activities (methodology), which result in technological objects (ontology).

## ***1.3 Excursions***

In educational circles an excursion, which may also be termed as a field trip, instructional trip, or school journey, is defined to be a trip with an educational intent, where students interact with the setting, displays, and exhibits to gain an experiential connection to the ideas, concepts, and subject matter (Behrendt & Franklin, 2014). According to Rennie (2007) as cited by Behrendt and Franklin (2014) there are two kinds of excursions. Formal excursions which consist of planned, well-orchestrated experiences where students follow a specific programme and informal excursions which are less structured and offer students some control and choice concerning their activities or environment.

During excursions students are taken to locations that are unique and cannot be replicated in the classroom. Each student observes natural (industrial) settings and creates personally relevant meaning to the experience. In some cases, interactive exhibits help students grasp concepts and activities often not possible in the classroom. Earlier course content suddenly becomes relevant as students assimilate and accommodate new understanding and cognition (Behrendt & Franklin, 2014). Lei (2010), reasons that the connection between the excursion venue and the classroom links the excursion's experiential learning with prior experiences and learning from the classroom. Mitchie (1998) claims that these kinds of activities enhance students' understanding of the processes involved and also improve students' attitudes towards the subject. Rennie and McClafferty (1995) argued that visitors (students) construct their own unique meaning for the visit experience according to personal background and interaction with the social and physical environment.

As suggested in the literature (Rennie & McClafferty, 1995), when planning excursions, it is important that they should be included in the applicable teaching programme. Apart from administrative requirements, this meant that planning started well ahead and the outcomes of each excursion could be integrated with those of the teaching programme.

According to Mitchie (1998) excursions are normally planned with the following objectives in mind:

- to provide first-hand experience,
- to stimulate interest and motivation in the subject,
- to add relevance to learning and interrelationships,
- to strengthen observation and perception skills, and
- to promote personal (social) development.

By exposing the students to the design and make processes in the various industries the expectation was that they would acquire mainly conceptual technological knowledge about and understanding of these processes which may improve their attitudes toward technology as concept appears to influence affect (Ankiewicz, 2016).

It was decided to introduce appropriate excursions (formal) to curriculum-related industries as a form of learning from practice to supplement the largely lacking volitional aspects in the curricula.

#### 1.4 Problem statement and purpose of the study

However, after the introduction of formal excursions over a period of three years, and although it has been planned to develop students' attitudes towards technology, we do not know to what extent it succeeds in doing so. The purpose of the research was to determine to what extent the formal excursions succeed in developing student teachers' attitudes towards technology. The research question that underpinned this research was: To what extent did the formal excursions succeed in the development of student teachers' attitudes towards technology?

## 2. RESEARCH DESIGN

The research approach was qualitative. The participants comprised technology student teachers from two cohorts. The first cohort consists of four students (two male and two female) who undertook two formal excursions in their third year and two formal excursions in their fourth year of study. The second cohort consists of eight students (two females and six males) who undertook two formal excursions in their second year of study.

Organising an excursion is not an easy task and must be preceded by good planning (Behrendt & Franklin, 2014; Mitchie, 1998). Logistics include aspects such as the finding of suitable dates, day of the week where the majority of the students do not have any lectures, consent from students to take part in these excursions, liaise with the contact person about what the students will see and experience, clothing suitable for the excursion, transport, and funds to cover expenses, e.g. fees payable to visiting companies (if applicable), transport and refreshments.

Without any exception all the excursions start with an introduction by the person in charge from the company, briefing the group about the history and explanation of what the core business of the specific company is about. Thereafter the students were taken on a guided tour, through the facility, or be involved in skills development facilitated by the person in charge. Table 1 shows the various excursions undertaken with the two cohorts over a period of three years.

Two sets of data were collected. Cohort one submitted written reflections on their experiences of the excursions. Cohort two completed an open-ended questionnaire reporting on their experiences of the excursions attended by them. The data gathered were analysed through the constant comparative method (Merriam, 1998). The students were also observed by the accompanying lecturers during the excursions. By using more than one method of data collection (reflections, open-ended questions and observation) the researcher ensured trustworthiness of the findings (Creswell, 2005).

Table 1. Layout of excursions undertaken by the two cohorts

Cohort	Year and year of study	Company	Core business of the company	Purpose	Link with curriculum
1	2015 3 <sup>rd</sup> year	Aerosud	An aeronautical company that manufactures components for Boeing and Airbus.	A guided tour where the students experienced first-hand material processing such as thermoforming, composite materials, sheet metal work, and product assembly. A strong emphasis is placed on safety and quality control.	Conceptual knowledge: Processing (EGTE1A, 2A, 3B) Mechanical systems and control (EGTE1A, 2A) Safety (EGTE1A, 3A, 3B, TMP3B)

Table 1. Layout of excursions undertaken by the two cohorts (continued)

Cohort	Year and year of study	Company	Core business of the company	Purpose	Link with curriculum
1	2015 3 <sup>rd</sup> year	Bosch – power tool training centre	The Power Tools Division of the Bosch Group is one of the world's leading providers of power tools, power tool accessories and measuring tools.	In making a small wooden project, students were exposed to the use of various power tools as well as basic joining. Assigning them to teams, working and assisting each other, they also experienced a teamwork element as well.	Conceptual knowledge: Measuring and tool skills (EGTE2B, 3B, CTE1A, 1B) Safety (EGTE1A, 3B, CTE1A, 1B, 2A) Procedural knowledge: Making a product (EGTE1A, EGTE3B, CTE1A, 1B, 2A)
1	2016 4 <sup>th</sup> year	Sentech	Sentech is the signal distributor for the South African broadcasting sector. Presently Sentech broadcasts 18 FM stations and seven TV stations.  It was the first test site for digital terrestrial television transmissions in SA.	The students observed transmitters converting audio signals from the studios at the SABC into radio frequency signals that are amplified and transmitted from the antennae on top of the tower.	Conceptual knowledge: Electronics (EGTE3A) Electrical systems and control (EGTE3A)
1	2016 4 <sup>th</sup> year	Eskom – Lethabo Power Station	Eskom generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors.  The Lethabo Power Station comprises of six 618MW production units. A Production Unit consists of one boiler, a turbine and generator. Power is produced at 20kV and at 13.5kA and send to a step-up transformer where the voltage is increased to 275kV for efficient transmission.	The students undertook a guided tour through the power station where the process of electricity generation was explained to them. The tour included the coal consumption, the crusher, the furnace, the boiler, the turbine, the generator, the transformer, the cooling tower, and the chimney. Students received information regarding the impact this power station has on the environment. This power station represents a major step forward in the utilisation of low-quality coal, and the water management system is designed specifically for the treatment, re-cycling and re-use of water.	Conceptual knowledge: Electrical systems and control (EGTE2B, 3A, CTE2A) The impact of technology (CTE2A, TMP3B)

Table 1. Layout of excursions undertaken by the two cohorts (continued)

Cohort	Year and year of study	Company	Core business of the company	Purpose	Link with curriculum
2	2017 2 <sup>nd</sup> year	Bosch – power tool training centre	The Power Tools Division of the Bosch Group is one of the world's leading providers for power tools, power tool accessories and measuring tools.	The students were exposed to practical skills regarding the use of power tools that are common in various industries. They were also exposed to new technologies, such as laser technology. They practiced skills such as drilling, cutting, grinding, screw driving, etc. into various materials.	Conceptual knowledge: Tool skills (EGTE1A, CTE1A, CTE1B, 2A) Safety (EGTE1A, CTE1A, 1B, 2A)
2	2017 2 <sup>nd</sup> year	Nissan SA	Nissan SA plays a major role in Africa by supplying the Japanese group's vehicles and assembly kits into the region. The Nissan SA plant at Rosslyn, near Pretoria, currently produced the NP300 Hardbody one-ton pick-up, as well as the NP200 half-ton pick-up.	The students undertook a guided tour through the plant where they experienced the complete production line of the NP200 half-ton pick-up. Safety, quality control, discipline in the workplace and production times were some of the aspects that were emphasised.	Conceptual knowledge: Mechanical systems and control (EGTE1A, 2A,) Safety (EGTE1A, 2A)

### 3. RESULTS

To determine whether formal excursions can complement the curricula for the academic majors as well as the teaching methodology and practicum (PCK) modules, regarding the development of student teachers' attitudes towards technology, Cohort one was asked to write brief reflections on their experiences regarding each of the excursions they had attended. Cohort two had to respond to the following open-ended question:

Tell us about your experience of the Bosch excursion compared to your experience of the Nissan excursion.

The main finding was that the excursions served as a means to compensate for the lacking volitional aspects in the curricula for the academic majors as well as the teaching methodology and practicum (PCK) modules.

The students enjoyed the excursions and found them to be valuable:

It was also **exciting** to see how the things we were taught about in technology being practically applied.

Bosch experience was more **fun** because it had active activities for the students.

This excursion **helped** me develop personally as a teacher.

... it was very **satisfying** to have a finished product to take home and share what you have learned with others ...

I am eternally **grateful** for the hands-on experience.

Both excursions were **meaningful** and have contributed a great deal towards my learning experience.

This is definitely needed in any form of technology education, to show learners how what they learn is applied in real-life situations.



The affective and knowledge components of student's attitudes towards technology were developed (Refer to Table 2).

Table 2. Summary of the attitudinal components developed by the students

<i>Students' attitudes towards technology were developed</i>		
<i>Attitudinal components:</i>	<i>The affective component of students' attitudes was developed</i>	<i>The knowledge component of students' attitudes was developed</i>
<i>Aspects of attitudinal components:</i>	<i>Students' interest in technology was developed Students developed an understanding of the impact of technology</i>	<i>Students gained conceptual technological knowledge Students gained procedural technological knowledge</i>

### The affective component of students' attitudes was developed

According to the responses from students, the excursions developed the students' interest in technology as well as their understanding of the impact of technology:

It was very **interesting** to see the various tools and equipment that is used to machine these parts and also to see how precise and organized these processes were.

It stimulated my **interest** in materials processing and motivated me to show my learners how the processing aspect of technology is actually used in the world of work ...

I did not have a profound **interest** in aircraft but, being there and being exposed to the machinery and the manufacturing aspect of it was very interesting to me.

The excursion reignited my **interest** in electrical technology because everything that is used there is part of electrical technology.

The excursions were really quite **interesting**, even in the cases where it was not about something that I had a general interest in and they catered for everyone and could stimulate an interest in you.

It was also **interesting** because I could relate it to the EGD content (assembly drawings).

This really made me think about the **ethical side** of technology and how one should make the greatest effort to make technology **safe for the environment**.

... the **implications** that come with generating electricity like the amount of water used.

### The knowledge component of students' attitudes was developed

Students gained conceptual technological knowledge:

... gave me first-hand experience of how technology can be used to make everyday products.

This excursion opened my eyes to what technology is and broke the misconceptions I had about what plastic can be used ...

I learn something new and I really enjoy this field (broadcasting) of technology.

It also showed me the interrelationship between technology and electrical technology.

This excursion was very insightful because it showed us how the electricity that is used every day is generated

Students experienced the development of procedural technological knowledge, which entails the thinking and technological processes:

The fact that I got to go home with a product that I had made with my own hands while I was on the excursion was the best part of the entire excursion.

On the Bosch excursion, we learnt a lot about the tools and materials and how to use them and the safety measures.

... taught us to use their tools correctly ...

I could relate this practical lesson to theoretical knowledge I have received about strengthening and finishing techniques of different materials ...

I was able to process a material to create a product but I used tools to make the final product.

During most of the excursions we saw relation that Technology learning content had to the industry in that, the principles we learn through the Technological Process.

I learned a lot and that improved my thinking capacity.

The researcher also observed the following:

- Students were very eager to go on these excursions.
- The majority of students were mainly on time.
- They showed interest in the different industries visited.
- They asked well thought out and relevant questions.
- They participated enthusiastically in hands-on activities.

Students realised that the outcomes of each excursion could be integrated with those of the teaching programme:

I think this excursion would be great for learners who take electrical technology as subject at school, as it makes everything they learn in class make sense.

#### **4. DISCUSSION AND CONCLUSION**

With the evaluation of the technology curricula at the university concerned it was discovered that no volitional aspects towards technology were addressed (Ankiewicz, 2015). Subsequently, appropriate formal excursions to curriculum-related industries, as a form of learning from practice, were introduced with the intention that it will compensate for the lacking volitional aspects in the curricula.

The purpose of this study was to determine to what extent the formal excursions succeeded in developing student teachers' attitudes towards technology. Analysis of the written reflections and open-ended questionnaires revealed that the students enjoyed the formal excursions and found them to be valuable. According to De Swardt, Ankiewicz and Gross (2010), enjoyment encourages learning. It was also revealed that the affective (volition) and knowledge components of student's attitudes towards technology were developed. In this regard, Svenningsson et al. (2018) argued that positive attitudes toward technology correlate with students' knowledge. According to Ankiewicz (2016) and Rohaan et al. (2010) it is clear that a clearer concept of technology among students will have a positive influence on their attitudes toward technology.

There was general agreement between the students and accompanying lecturers that these formal excursions were valuable for the students' cognitive and affective (volition) development. According to Mitchie (1998), participating in excursions affected student learning and their attitudes, both towards the subject and personally, and enhanced their behaviour. Although the behaviour component was not addressed, it can serve as a starting point for a future research project.

When comparing to the criteria developed to evaluate the volitional aspects of the curricula (Ankiewicz, 2015) it can be reported that the outcomes of the formal excursions comply with criteria V1, V2 and V4. In the light of the above, it can be argued that the formal excursions succeeded in improving students' volition towards technology and it can be used to compensate for the lacking volitional aspects in the curricula for the academic majors as well as the teaching methodology and practicum (PCK) modules.

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# Making Industrial Internships Effective for the Professional Development of Aspiring Science Teachers

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“As our industries struggle to remain competitive in a world market and educators struggle to prepare our students for careers that may not even exist yet, it is becoming apparent to executives and teachers that education and industry must work together.”

Ann Farrell, 1992.

## 1. CONTEXT OF THIS CASE STUDY

At the teacher education institute of Fontys University a course was designed to make student teachers more aware of the relevance of their school subjects for their future pupils' working careers. We advocate that teachers should have knowledge about workplace contexts that are related to the school subject they will teach, to be able to address the talents and interests of their pupils and to make their teaching more relevant. Stuckey and colleagues note that an important reason for students to lose their interest in (studying) science is that “learners perceive science and science education as irrelevant both for themselves and for the society in which they live and operate [...]. As a result, science teachers are required to make education more relevant in order to better motivate their students and interest them in science subjects” (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). Following from this line of thought, we designed a course that aims to challenge our student teachers to expand their knowledge of the future workplaces of their pupils.

The initiative for creating a course with that goal in mind was strengthened by a sense of urgency: many of our current student teachers enroll in teacher education programmes directly after finishing secondary school. In most cases, they will start teaching jobs in secondary schools directly after graduation. This academic route makes it possible for them to become teachers without having much knowledge of, or experience in, professional workplaces outside the field of education. That makes it difficult for these teachers to mentor their pupils in making valid and informed career choices. Furthermore, this lack of experience could hinder them in showing their pupils the relevance of science and technology. Internship experiences in non-educational contexts could aid student teachers and can also easily be justified as an essential part of the curriculum. It could, for instance, help them to expand their content knowledge by adding knowledge of relevant workplace contexts to their (elaborate) knowledge of school subject matter, thereby enriching their own images of science and technology in daily practice.

The bachelor-level course we designed was primarily aimed at prospective physics, chemistry, and biology teachers, but some student teachers from other disciplines (mathematics, economics, and health) also opted to take this course as part of their curriculum. All of the twelve student teachers that chose to take the course were enrolled in bachelor programmes that prepared them to become teachers in lower secondary education.

## 2. RESEARCH FINDINGS RELATED TO TEACHER INDUSTRY INTERNSHIPS

The course was designed in a more or less pragmatic approach. It was not informed explicitly by academic notions on teacher industry internships but was designed and implemented by a teacher educator who had extensive practical experiences in connecting educational and industrial practices. As this paper primarily

serves as a means to share our reflections on the course, we will discuss several academic sources that helped us during these reflections.

Studies devoted to describing (student) teacher learning through industry internships appear to be rather scarce. The few studies we found however, started from the same issue we encountered. Bowen (2013; cf. Bowen & Shume, 2018) states this issue as follows:

“[T]eachers who receive licensure through a traditional university educational program typically do not have corporate work experience. By placing teachers in a corporate work environment, they can gain valuable first-hand knowledge [...]. The teachers can then take this knowledge back to the classroom to make the course content more relevant for their students through real-world application of the teacher's experience.”

One of the most notable studies on teacher industry internships was conducted by Farrell (1992). She studied 18 maths and science teachers taking up industry internships during their summer holidays. Her study consisted of an analysis of the reflective writings of these teachers. One of the main findings was that the teachers involved seemed to learn about the skills required to work as an industrial professional and how they differ from the skills required to succeed as a student in (traditional) science and mathematics education:

“As they became part of company teams working on projects, the teachers looked for mathematics and science applications they could take back to their classrooms. All of the participants found these applications, but even more exciting (and unexpected) was the value they discovered in adapting their teaching methods to include more cooperative learning, open-ended problem solving, writing, and technology in order to better prepare students for careers in business and industry.”

The necessity of ‘soft skills’ for industrial professionals can also be found in more general research on workplace learning and professional competences. Jeroen Onstenk (1997) for instance, conducted several extensive and in-depth studies on workplace learning. In his studies, he focuses on the learning potential of workplace settings and key issues workplace learning entails for professionals. Onstenk presents us with a model of professional competence consisting of eight types of skills, of which subject related skills are only one aspect. The width of professional competence also makes it difficult to set very strict goals for an internship, because the learning potential of the workplace will differ widely between different work contexts. A common theme however is that every professional faces ‘key problems’ (Meijers, Kuipers, & Bakker, 2006) that entail ‘professional dilemmas’. We would argue that (student) teachers as part of their industry internship should be able to (learn to) recognize these key problems and associated professional dilemmas and find ways to bring these into the classroom as part of their everyday teaching.

Looking from the perspective of students in secondary schools, Braund and Reiss (2006) discuss the importance of learning experiences outside school. This impacts the course two-fold. It underpins the relevance that student teachers themselves have to get learning experiences for their own development, and the importance that they also can develop these learning experiences for their future pupils. They argue that extracurricular learning as part of the science curriculum, validates the curriculum for pupils and develops therefor more motivation: "We support such changes but argue that far greater use needs to be made of out-of-school sites in the teaching of science. Such usage will result in a school science education that is more valid and more motivating." In addition, they address the added value for meaningful science education. And they set the condition that the experiences should be shaped in a way in which it is also meaningful for pupils. They also mention the relevance of developing the inquiring attitude of pupils. This fits well with what Jeroen Onstenk (Onstenk, 1997) said about the key problems or professional dilemmas. Because open research fits like job related challenges for higher educated professionals.

### **3. COURSE DESIGN**

The focus for the designed course was set to develop the self-management ability of student teachers in shaping their final products. There were not many final requirements for the final product so the student teachers had to relate themselves to their final product. The rationale for this can also be seen as representative for developing a professional attitude, that fits a learning professional. Jeroen Onstenk (1997) mentioned that the informal nature of workplace learning stresses the importance of the learner's role in managing the learning process: learning is

not directed by an external organization. Instead, workplace learning takes a more autonomous and spontaneous form.

The course lasted for a period of eight weeks. To prepare the students, they received an email eight weeks before the course started, in which they were invited to start searching for a company for their internship. They were also offered support in doing that. The internships should total forty hours and the task was to design an educational experience, that this company could use in their cooperation with schools. During the period we had three intervision meetings. One at the start, one at the middle of the period and one at the end. At the end the students delivered a rapport which included a diversity of assignments and their final product. During the period the teacher educator visited the students at the companies.

## **4. ASSIGNMENT DESIGN**

### ***4.1. Research on the assignment***

The conversations with teacher educators addressed that there were many doubts about the design of the course. The questions were about the organization and the content. Those questions did not touch the essence of the complexity of the course design. These were accountability discussions. Most comments came from Economics, but there was also a possible approach: the development of case studies for Economics lessons.

Adjustments on the course based on the research of the assignment

Everyone understood that lessons about companies had to be developed. The fact that the pedagogical choices had to fit with the operation of the company, was less well understood. That was the innovative step I wanted to achieve within this course. So I tightened the final terms for the course by making them more explicit.

- Student teachers should be able to arrange an in-company internship. They need to enlarge their knowledge about companies in general and within the national context. That would make it easier for them in future, to be able to find the fitting companies to work with.
- They must design a teaching experience that is representative for the company and usable in the classroom. The pupils should learn something that they need to have learned to be able to work at the company. Focus was set on the metacognitive skills. We call this the future skills.
- The student teachers will also be asked if they had a vision on how they think that working with companies can contribute to the orientation of students at their future field of work.
- These insights should the student teachers acquire during the process itself and it should challenge them to design their own criteria for success. The final product presents evidence for the acquired learning goals.

### ***4.2. Design choices to develop the course***

The student teachers who participated at the course are nearly independent professionals. Teachers design their education to their own personal standards and to developing these standards should also be challenged to the student teachers to formulate their own standards. On this consideration, I abandoned the assessment matrices that are commonly used by teaching training assessments.

In order to get an appropriate assessment for the course I've developed a guidance framework with a few number of points, which I have considered the final products. This consideration I have written out, so that the underlayment for the final mark would be clear. This is also to help them to broaden their perspective on their personal standards. See also the theoretical framework about self-management.

At the start of the course we spoke extensively about the learning goals for the course to match the pedagogical contract. Learning and not judging is the mindset during the course. And to be able to develop their self-management they were challenged to work towards a convincing final product. These talks were essential for the establishment of the pedagogical contract. To provide the student teachers guidance during the course I've written an extensive study guide. In this study guide they could read what the objectives are for the final product, which literature was recommended, what the commands were they can use to work towards the

objectives and what we were going to do during the meetings. However, they had the freedom to reject the commands, as themselves could provide a more meaningful alternative. That was part of the pedagogical contract.

For the guidance I wanted the responsibility for the organization of an internship, placed by the student teachers themselves. They can, after all, oversee the best when a visit has most added value. The intervision meetings had to fit to the tasks they had at that time: starting-up, developing content, finalization. In general I've been their coach by taking personal responsibility and to take their professional role.

#### ***4.3. Education design meetings***

During the intervision meetings we took the individual learning experiences of the student teachers and them brought together to get a general understanding about the process they went through. In this way, the learning outcomes were abstracted and made usable for student teachers in new situations and effective.

During the last meeting the student teachers were given the opportunity to ask the last questions about their final product. The pedagogical contract tells that the student teachers should answer these questions themselves. They wrote their questions down and asked the other student teachers for answers. Noteworthy was that all groups had similar questions and the similar answers. It was, above all, uncertainty. They knew the answers to the questions themselves.

The student teachers asked for a rubric for their final product to be evaluated. But we had agreed that they would deliver a product that would fit to their own standards. This choice made sense because the in-company internship experiences, they learnt that within the company there are also no assessment matrices for professional handling. This friction is very similar to the friction that Koeno Gravemeijer addressed in his article on the pedagogical contract. But by consistently acting the student teachers accepted this thinking and practices.

#### ***4.4. Research whether the student teachers learning yields fit to the desired learning goals***

The learning yields show that the chosen strategy for the pedagogical approach for de course fitted by the desired learning goals. The student teachers had a personal learning path and acquired learning yields that could be connected to the learning yields described in the final terms.

There appeared to be quite notable differences between the student teachers from different training programs. All student teachers managed to find a suitable in-company internship, and delivered a final product that included an educational experience that is representative for the company and usable in the classroom. Focus was the development of an appropriate skill for solving a professional dilemma. The dilemmas that the students addressed were partly people skills, collaboration skills and partly subject related skills. This is in line with the skills mentioned bij Ann Farrell (1992). The design of the educational product had contributed to the development of the student teachers by creating an own view on how they think that companies and schools should work together.

#### ***4.5. Reflection on the design choices***

Releasing the assessment matrix did not provide problems by the judging of the students products. The student teachers did recognize themselves in the marks they obtained. During the meetings it became clear to me that the student teachers population and their prior knowledge was very diverse, and that mattered significantly for the quality of the final products. By not using an assessment matrix, the evaluation probably focuses more on the process, then on the final terms.

I provided the student teachers the chance to work out the commends in a way it would be meaningful for themselves. The better student teachers took that opportunity. The uncertain student teachers remain close to the commands. Also some student teachers choose the easy way and work to the superficial.

A number of student teachers had no in-company internship visit settled. The evidence of their learning outcomes had to be much more convincing in their final products. The student teachers would like to have had more meetings, especially on the developing of the educational product. Most student teachers were already well able to self-steer their learning and but there were too unsure to do so.

## **5. CONCLUSIONS AND REFLECTIONS**

### ***5.1. Learning outcomes of the teacher educator***

The assignment to design an educational experience that is about the company, and also features in the pedagogics of the company, appeared to be difficult to explain to other teacher educators and student teachers. The importance of connecting the future work field in the curriculum is understood. Also the development of future skills at high schools is widely and socially recognized. The concept that student teachers develop educational programs that fits the skills from the work field is however less quickly understood, by both teacher educators as student teachers. Probably because there are too few good practices known in the field of work of education.

The student teachers are used at being judged for open commands with an assessment matrix. They use these to design their final product. The removal of this grip creates uncertainty among student teachers about what to deliver. In the beginning of the process, the student teachers opened to this approach, but as they got closer to completion, they increasingly needed a handhold. At that time they only experienced what self-management meant, when designing. To keep the student teachers committed there is a strong and clear expressed belief needed, on which the principles are formulated.

As a teacher educator, I designed an educational experience for student teachers, in which I have chosen for a strong process control and less control on final product requirements. I did this because I think that this is more appropriate for learning skills, such as self-steering ability, communication skills and design skills. From the student teachers I expect that they design educational products, where pupils develop process skills. The experiences I am attending at the design and implementation of teaching and researching its effects, shows that this strategy contributes to the learning of student teachers. That is why I let the student teachers themselves also design educational product, so that they also experienced how instructive it is to design and research. And I hope they will provide these learning experiences to their pupils.

By the student teachers out-of-school experiences and by the learnings on how to create meaningful education, I hope that they feel capable to start developing out-of-school experiences for their pupils. Endorsed by their final product I conclude that they recognize the added value.

The design approach helped me to align my final terms with the pedagogical approach. It also helped me to look more closely to my list of requirements before writing the study guide. The inquiry learned me to look very closely to the learning outcomes, and to see if my guts feeling fitted the realised outcomes.

The student teachers were not used to this level of self-management. At the start of the course we discussed this extensively with the student teachers. This discussion is the drawing up of the “pedagogical contract”, which the student teachers also addressed. This concept of “pedagogical contract” is extended mentioned by Gravemeijer (1995). The article describes the bottlenecks that are experienced with changed teaching methods in mathematics education, and indicates the concept of pedagogical contract and the challenges of teaching with a changed pedagogical contract. The specific character of the pedagogical contract makes that it is not enough to tell the pupils about the new social standards; the new standards should also be embedded in daily experiences.

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# Constructs of Quality and the Power of Holism

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This paper concerns the process by which learners come to understand the meaning of quality in design & technology. This sense of quality is central to learners' development of autonomous technological capability, and equally to teachers' ability to make good judgements about the progress of their students. Underpinning it all is *assessment*, which is – after all – just about deciding what counts as 'good' and what as 'not good' or 'less good'. This is problematic because all sorts of different things might be good or - equally – bad. So it is a complex matter to be able to say that this piece of work is good, and that one also is good, but for quite different reasons. Or that this one (which contains X) is good, whilst that one (which also contains X) is poor. For students to develop this complex sense of 'good' it is they who must do the assessments so that they can evolve their view about quality and endlessly share it – and refine it - within their community of practice. The approach is not criterion-based assessment, nor norm-based assessment, but is better described as construct-based assessment, in which learners hold a multi-dimensional construct (an explanatory variable that is not directly observable but that nevertheless is real and useful) of what counts as quality and that enables them to discriminate between one performance and another. This is especially important in performance disciplines where the fact that '*the whole is more than the sum of the parts*' renders reductionist methods at best inefficient and at worst invalid.

*Key Words: Constructs, holistic assessment, quality, judgement, connoisseurship.*

## INTRODUCTION

This piece is not based on new research, but is rather compiled from pieces previously presented by myself and by others ... and usually for other purposes. They are like chapters in a story and it has only been in retrospect that I have come to see the connections between these chapters and the significance of them for the central story. And the key question is 'how do learners get to know what counts as *good*?' I shall argue that learners progressively construct their own sense of quality.

## CHAPTER 2

The National Curriculum was launched in England in 1990, and it created enormous uncertainty. The explicitly procedural Attainment Targets (ATs) and Statements of Attainment (SoA) for design and technology appeared to provide little guidance on the critical matter of what (ie what content) should be taught. And the whole shooting match was utterly undermined by a ludicrous assessment system designed by Paul Black and colleagues in the Task Group for Assessment and Testing: TGAT. (see DES/WO 1987). Performance in technology alone was defined through 150 SoA, each of which had to be ticked (or not) from a list. The number of hits and misses was then subjected to a formula (several version were tried:  $n-1$  and  $n/2$  being the favoured ones) to decide what level of performance the learner had achieved. It was so cumbersome and so utterly inappropriate that in 1992 teachers and schools completely refused to administer any of the assessments. There was a solid national boycott of the whole thing and the Minister responsible for the shambles was forced to resign (for a full account see Kimbell 1997 ch5).

One of the key problems in the NC documents was that they were so enormous; so wordy; and so opaque. The best-intentioned teachers found it really hard to make sense of it all. So in 2000, in what must have been about version 5 of the NC, there was an important addition. For each subject there was a brief holistic description of the 'distinctive contribution' of the subject in the curriculum. It was intended to clarify not just what d&t is, but also why it is worth studying. And it did it in 120 words.

Of course in the run-up to its publication it was the most fiercely argued 120 words ever produced in design & technology. There was blood on the walls in the editing room as versions were cut and edited. I thought that the final version was a terrific statement. Both helpful and visionary. And it taught us all an important lesson... that a simple holistic descriptor can do so much more than all the kgs of ATs and SoAs that (by that time) were discredited and ignored by teachers.

## Chapter 2

A few years before the NC was launched we at Goldsmiths were running the APU assessment project – attempting to assess the d&t performance of 15 yr olds in England, Wales and N Ireland. Having developed the tests we were struggling to create a mark scheme and were faced with the perennial challenge of assessment “How should we describe *quality*?”.

We decided to reverse engineer it. We asked our teacher/markers to make a holistic judgement about the quality of each portfolio. The holistic judgements were on a 6 point scale, and we used them to create piles of work with reasonably high scores (4ers) and piles with reasonably low scores (2ers). We then took pairs of scripts (one 4 and one 2) and compared them to see what ‘better’ pieces were doing that ‘poorer’ pieces were not (and vice versa). And we did that many, many times.

While the holistic mark enabled us to value a piece of work, the yes/no (secondary analysis) provided us with a composite description of it.... We coined the expression ‘fingerprinting’ the scripts because, like a fingerprint each script was unique, but by building up a list of discriminators it became possible to describe that uniqueness in any particular script. (Kimbell et al 1991 p32)

So, rather than impose an assessment framework onto the work, we *drew it out* of the work, with the holistic judgement being at the heart of it. But how did the markers make these judgements? They were not informed in advance by criteria, and yet we – and our team of teacher/markers - could agree on them with remarkable reliability. In fact, having developed the whole assessment framework, our markers were consistently more reliable in making their holistic judgements than they were when attempting to assess components of capability.

## CHAPTER 3

It was in 1994 in the immediate aftermath of the NC assessment crisis in England that Dylan Wiliam wrote a set of pieces about criterion-based assessment. We had worked together for three years within an assessment consortium preparing NC SATs tests, and we were all scarred by the process of trying to make sense – for teachers – out of the agonising nonsense that had been created by TGAT. In the light of many trials of assessment tasks and their marking, Wiliam commented ..

To the extent that the examiners agree, they agree not because they derive similar meanings from the regulation, but because they already have in their minds a notion of the required standard. The consistency of such assessments depend on what Polanyi (1958) called *connoisseurship*, but perhaps might be more usefully regarded as the membership of a community of practice (Lave & Wenger, 1991). (Wiliam D 1994 p6)

..because the assessment system relies on the existence of a construct (of what it means to be competent in a particular domain) being shared among a community of practitioners (Lave, 1991), I have proposed elsewhere that such assessments are best described as ‘construct-referenced’ (Wiliam D 1997)

Interestingly, Eisner (2002) has also used the term *connoisseurship* in the context of assessment. He defines it as the art of appreciation, though he is careful to make the distinction that appreciation does not exclusively mean to like something. Rather, it consists of “recognizing and appreciating the qualities of a particular,” (p. 215). In complex portfolio assessment I think it is even more than that. It is seeing the qualities in relation to each other and how they impact on the whole.

In this troubled time of criterion-overload, Polanyi’s (1958) view of *connoisseurship* is particularly interesting. He points out that “*connoisseurship*, like skill, can be communicated only by example, not by precept” (Twietmeyer 2012; Polanyi 1958 p56).

All those useless and discarded National Curriculum Statements of Attainment (i.e. criteria) are precepts, and the normative words that they invariably use (thorough, reliable, excellent, complete, etc etc etc) utterly fail to capture any sense of quality because precepts are infinitely adjustable to any user group. I can say a piece of writing by a 6 yr old is excellent – whereas that from a 16 yr old is only adequate – though of course superior to that of the 6 yr old. Polanyi is dead right; we cannot define quality in words (precepts). If however we look at the two pieces of writing (the real [Polanyi] examples) the differences in quality are obvious.

In any event, Wiliam's notion of 'constructs' sits very comfortably with Polanyi's connoisseurship and each of them sits well with the holistic nature of assessment that we had created for APU and then used for NC assessment. It sounds plausible that the holistic judgements that our teachers were making – pretty reliably - were informed by a common construct that they held about what 'quality' means in design & technology. The big question was where does this construct come from ... or how do we acquire Polanyi's connoisseurship?

## CHAPTER 4

Within the e-scape project (2005-10) we created a web-based assessment tool that relies on comparison to identify quality. Without specifying any criteria for excellence, teachers were presented with pairs of portfolios and were asked to identify for us 'Which of these two portfolios is better'? They had no difficulty in doing so and they made many comparisons that the tool then translated into a rank-order of quality.

In the 2009 national trial – with 350 portfolios and 28 judges – we rapidly arrived at a rank order with a reliability statistic of 0.95. This is an astonishing statistic. Absolute reliability about a set of multi-media portfolios that portray creative designing activity by 350 learners. Never before has it been possible to produce this level of reliability with such data. And all the conventional paraphernalia of assessment was gone. No extended scoring sheets ... no allocation of marks and painful calculation of overall scores... no 2<sup>nd</sup> markers and disagreements ..... no moderation.

All the judges had to do – in relation to each of the pairs of portfolios sent to them - was to say 'this one is better than that one'. End of story. Our teacher/judges thought it was wonderful and were delighted that they had contributed to such an astonishingly reliable outcome.

(Kimbell 2012)

This is evidence of teachers holding some version of a common construct of quality. By virtue of their experience as design & technology teachers they are participants in the 'd&t community of practice' and - we might argue - have developed Polanyi's connoisseurship. But it is not quite that simple.

## CHAPTER 5

It was Becher and Towler (2001) who first introduced me to the idea of 'tribes' in education. Their book *Academic tribes and territories* is an enquiry into the nature of the linkages between academic cultures (the 'tribes') and disciplinary knowledge (their 'territories'). The label 'tribes' is very deliberate and is redolent of customs and traditions, informed by articulated values (as well as knowledge and skill), and ruled over by High Priests (as arbiters of belief).

The tribes label fits neatly with my experience of design & technology, not because it IS a tribe, but rather because it contains a series of tribes. Or perhaps a series of sects within a bigger tribe. The creative designers ... the geeky techno's ... the craftsmen. And these sects are driven by somewhat different values. So when a team of d&t teachers set about marking or judging student portfolios, we should not expect them 'to be of one mind'. They have different intuitions. And inevitably they make somewhat different judgements.

To explore this idea, I selected 10 portfolios from a national sample of 350 from the e-scape phase 3 project. The ten portfolios (A-K below) were chosen because they caused more disagreement than any other ones among e-scape judges. I asked 11 colleagues (all experienced d&t practitioners and researchers) plus myself to a comparative judging session with them. We each created individual performance ranks and the mean of our individual ranks is shown in the final column. Fortunately there is a very high correlation (0.95) with the 2009 rank that was generated by all 28 judges looking at all 350 portfolios.

Table 1

	1	2	3	4	5	6	7	8	9	10	11	12	Mean
A	7	4	1	2	2	1	3	2	2	2	3	1	2.64
B	3	1	2	6	4	4	2	7	1	7	4	4	3.73
C	5	2	4	1	3	5	1	3	3	5	7	2	3.55
D	2	8	3	4	5	3	4	1	7	3	1	3	3.73
E	1	5	5	5	1	2	7	5	9	6	2	8	4.36
F	8	3	8	3	7	8	5	8	6	9	6	9	6.45
G	4	7	6	7	9	6	6	4	4	10	8	7	6.45
H	6	9	7	9	8	9	9	6	5	1	5	6	6.73
J	9	10	9	8	10	10	8	9	8	8	10	10	9.00
K	10	6	10	10	6	7	10	10	10	4	9	5	8.36

There are some very interesting results here. Judges 3, 7 and 12 have the same first 4 portfolios. Judges 3 and 7 have worked together for more than 30 years and they really are (often) of one mind on such matters. Judges 1 and 11 identify different star performers (D and E). They are apparently seeing the same excellence – but different from those of judges 3, 7, and 12. And judges 4 and 7 have identical views about the poorest performers.

This analysis was followed by a day of round-table discussions aimed at trying to identify the sources of the agreement and disagreement. And what emerged was the possibility of at least 3 sects in our tribe:

- *designers*: who prioritised the product and look particularly for user-appeal, are interested in ideas, and don't worry too much about the rules in the task.
- *teachers*: who focused on learners' designing *process* and valued it were it was more explicit and articulate.
- *examiners*: who focused on the rules of the task, because the rules are important and the evidence should fit the rules.

In reality, all of us belong to all of these sects. We are all (or have been) designers, teachers and examiners. But we prioritise our affiliations differently. This difference comes starkly into focus with portfolio E, which four judges decided was 1<sup>st</sup> or 2<sup>nd</sup>, while three other judges decided it was 7<sup>th</sup>, 8<sup>th</sup> or 9<sup>th</sup>. For a full account of this work, see Kimbell (2013).

## CHAPTER 6

Following from these examples of holistic judgement by teachers, I thought it would be instructive to explore what happens when learners are in the judging seat. A group of year 10 students involved in the e-scape project willingly had a go at this for us and with 20 pieces of work being judged by them, their emergent rank order correlated very highly (0.88) with that generated by the e-scape marker team of teachers. But it was learners' immediate comments that were so informative.

“Why didn't you show us this before we did our project .. I can see how I could have made my work much better”. (Kimbell et al 2009)

Naturally I responded with the question “... what do you mean by better?” And so the discourse kicked off.

There are two things to recognise about this. First, we had uncovered (quite unexpectedly) the power of this comparative judgement process as a tool for encouraging a discourse about quality. Beyond the discourse however, there is a second matter of significance. Since the learner and teacher ranks correlated so well, it is at least *prima facie* evidence that these year 10 learners did indeed hold a construct of quality quite close to that of their teachers. So was it so useful to provoke the discourse?

Of course it was, not so much to create the construct (which was already in place), but to encourage the learners to *articulate* it. They could say that this .. and that ... and this ... and that ... are components of it. And maybe also that when you see this in association with that its especially good. We know that, in design terms, the act of expression pushes ideas forward. So too with this discourse, the act of it begins to crystallise the construct for them. It makes a vague and intangible construct into something a bit more substantive. It encourages Polanyi's *connoisseurship* to take form.

## CHAPTER 7

In a subsequent piece of work inspired by the effects of using the comparative judgement tool with groups of learners, I explored the mechanisms that learners were using to make their judgements. This work was based on an analysis of many judges' comments as they were making judgements (in many different judging settings and with many different groups of judges), and on interview data drawn from discussions after the judging events.

Initially the judge approaches the work open-mindedly and maps it. Much like a surveyor marking out a field – with a stream – and a hillock – and fences. But this descriptive map is not a paper product like an Ordnance Survey map, it's a mental map. With pre-conscious associative memory working overtime, triggering emotional as well as intellectual responses, the map mutates from being just a neutral description of the field and rapidly becomes a value-laden depiction. But we are teachers and academics who value reason and argument. So we need to have evidence to formulate the decision that we know we are about to take. And we therefore seek concrete strengths and weaknesses that can be pointed to as justification for our decision. When we have found enough of these to be confident in our judgement – we declare the decision.

These three aspects of cognitive processing (mapping, characterising, validating) appear to operate concurrently.... (Kimbell R 2013)

It is not a three-stage process ... but rather an endless iteration between three priorities, and whilst *mapping* and *validating* appear to be more deliberately driven, the *characterising* is intuitive and largely beyond the control of the judge. Whilst *mapping* addresses the descriptive question 'what has this person done?' *validating* deals with the judge trying to be absolutely fair about their decision. 'If I give the vote to A am I being unfair to B?' Some judges take much longer than others to make their decisions. But there is no correlation at all between the length of time taken and the reliability of judges. I believe that the time variation in judging is simply that some judges are content with a moderate level of evidence – whilst others need to be quite sure before they make the decision. So they look deeper and take longer. For a full account of this work see Kimbell (2013).

## CONCLUSION

If I was a betting man, I would put money on the core of Polanyi's *connoisseurship* being tightly related to the nature of the characterising that I have described above. This is not a deliberate process but an inductive and intuitive one and it is shaped by associative memory. In 'Thinking Fast and Slow' (2011) Kahneman demonstrates how the brain uses *associative memory* to make sense of the world. The images, sounds, actions and relationships that surround us are both descriptive (what is going on) and normative, including judgements made by others and ourselves (I like this / hate that / that's funny / that's boring / that's great). Together – below the level of conscious attention – the brain associates these memories and links them into coherent patterns.

An idea that has been activated does not merely evoke one other idea. It activates many ideas, which in turn activate others. Furthermore only a few of the activated ideas will register in the consciousness; most of the work of associative thinking is silent, hidden from our conscious selves. (Kahneman 2011 p52)

(associative memory allows you) to maintain and update a model of your personal world, which represents what is normal in it. The model is constructed by associations that link ideas of circumstances, events, actions and outcomes that occur with some regularity. .... As these links are formed .. the pattern of associated ideas comes to represent the structure and events of your life, and it determines your interpretation of the present as well as your expectations of the future. (Kahneman 2011 p71)

As learners are inducted into the community of practice that is design & technology, they are bombarded with an endless panoply of experiences – shaped to some degree by the teacher and the school – and gradually learners' associative memory refines these experiences and gives them predictive power. This – I suggest - is Polanyi's *connoisseurship*.

Thus do our teachers make consistent judgements and thus do our learners also begin to make consistent judgements. They have spent years being inducted into our community and there is enough commonality in their experiences for more-or-less common constructs to form. Not only do they understand it consciously but their intuitions are also shaped by it. And their constructs take form much earlier than one might think. Canty et al (2017) report the reliability of undergraduate students in Ireland making judgements of their groups' work, but more recently Bartholomew et al (2018) report the same kinds of reliability with middle-school learners in the USA.

But the construct cannot work for us if we deny its existence. If we start from an atomised list of assessment criteria/bullet points – the construct is unable to make any sense of what we are looking at because our associative memory is by-passed. Our constructs are only able to work from example. Like wine-masters tasting, or diamond-sorters selecting, we can only diagnose quality when we see it. And - more than that – we need to see *all* of it. Holistic judgement is the only mechanism through which our constructs can work for us. The constructs of connoisseurs are cohesive.

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# Exploring the Potential for Identifying Student Competencies in Design Education through Adaptive Comparative Judgment

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Efforts to improve current educational practices and student preparation for future work and societal participation include a recent emphasis on competency-based education (CBE). Efforts to identify necessary competencies, prepare students to adequately demonstrate proficiency in these competencies, and align educational efforts with industry needs are all being undertaken. Despite an emphasis on these efforts, there is however, no consensus as to the best model, approach, instrument, or mechanism for assessing student competency-levels. Further, aligning industry needs with CBE approaches and assessment models has not been realized. This paper investigates several different potential approaches to CBE assessment through adaptive comparative judgment (ACJ), a relatively new approach to assessment which revolves around pairwise comparisons of student work rather than traditional rubric point-scoring.

*Key words: Adaptive Comparative Judgment, Competency-based Education, Design Assessment*

## 1. INTRODUCTION

Although the ideas and foundation for competency-based education (CBE) have been around for years, pushes for a competency-based educational approach have been increasingly common in recent years (Education, 2017). Proponents cite that understanding areas in which students are proficient and competent is more important than information obtained through traditional transcripts and grades (Thackaberry, 2016). Despite these calls, and the recent emphasis on this approach to education, there is no consensus around how to assess and/or identify student competence - especially in highly-creative or open-ended areas (Voorhees, 2002). However, recent advances in technology, and increasing attention to a particular approach to assessment called Adaptive Comparative Judgment (ACJ), may provide plausible solutions for assessing and identifying student competence in a variety of areas, including highly-creative and open-ended fields.

## 2. STATEMENT OF PROBLEM

Current educational paradigms, traditions, and practices, which emphasize rubrics and “points,” are not fully compatible for CBE assessment as CBE emphasizes competence rather than quantifying performance (Hoogveld, 2005). Despite these challenges, recent educational advances, particularly in assessment, have shown promise in addressing challenge assessment scenarios (McClarty & Gaertner, 2015). We sought to investigate the potential of ACJ, and the associated technologies, for the assessment of student competencies. Our efforts were guided by the following research objective:

RO: Exploring the Potential for Identifying Student Competencies in Design and Technical Education through Adaptive Comparative Judgment.



### 3. LITERATURE REVIEW

#### 3.1 *Competency-Based Education*

Today, in many professional fields, there is an importance in making sure that students are educated with not only the knowledge, but also the skills, to accomplish their goals (Thackaberry, 2016). As an approach, CBE has been around in education for over 40 years, but is currently being re-emphasized because of the need for highly skilled professionals (Education, 2017). One of the problems with CBE is that there is not high agreement on the definition for competency (Fletcher, 1997; Mansfeld, 1996; Roe 2002; Spencer & Spencer, 1993; Velasco, Learreta, Kober, & Tan, 2014). The definition may vary from subject to subject, and has faced criticism against its use in higher education (Lozano, Boni, Peris, & Hueso, 2012). Within higher education, there are several programs that have partnered with industry experts to insure that the student's curriculum meet industry standards and that students are "competent" (Johnstone & Soares, 2014). In this process, teachers are expected to move away traditional lecturing and step into the role of trainer or coach (Hoogveld, 2005) helping students demonstrate their competence in particular skills. CBE is especially prevalent in professional studies, such as medicine and dentistry (Holmboe, Sherbino, Long, Swing, Frank & International CMBE Collaborators, 2010; Yip & Smales, 2000), which rely heavily on demonstrated performance. Further, proceedings from the Competencies Conference (2002) were summarized and published (Kaslow, Borden, Collins, Forrest, Illfelder-Kaye, Nelson, ... & Willmuth, M. E. 2004) with three main themes identified as needing additional effort in CBE; these areas were: identification, training, and assessment.

##### 3.1.1 *Competency Based Education Assessment*

As CBE emphasizes preparing students for the professional world, CBE assessments can be vigorous and multi-faceted (Holmboe, et al., 2010). Voorhees (2002) explained that as CBE continues to grow in implementation, there is a need to move away from written assessments that do not fully capture skill. However, within education, there is disagreement between which party(ies) must develop new assessments which captures and/or identify the skills necessary for the professional world (Voorhees, 2002).

One CBE assessment that has been used is called "Modeling and Measuring Competencies in Higher Education — Validation and Methodological Innovations" (KoKoHs). The development of the KoKoHs, revolved around competencies being established through the cooperation of content experts and educators. This process revealed that, any CBE assessments established must be thoroughly tested before implementation for practice (Zlatkin-Troitschanskaia, Pant, Toepper, Lautenbach, & Molerov, 2017) to ensure proper identification of necessary skills. McClarty and Gaertner (2015) added to this idea, emphasizing the importance of aligning CBE assessments with the skills and knowledge that will be expected in any given professional field. Further, comparative judgment (CJ), a relatively new approach to assessment used in multiple areas of education, has demonstrated potential as a CBE assessment in skills-based programs (Coenen, Coertjens, Vlerick, Lesterhuis, Mortier, Donche, ...& De Maeyer, 2018) as the results from comparative judgments are traditionally significantly more reliable than other approaches to assessment (Pollitt, 2012).

#### 3.2 *Adaptive Comparative Judgment*

Comparative judgment assumes that a person will struggle when attempting to assign a value to a perceived phenomenon (e.g. the weight of an object, the temperature of a room, or the quality of a painting). However, Thurstone proposed that instead of assigning values, a person can more reliably and instinctively identify the 'better' of two compared phenomena (e.g. the heavier object, the warmer area, or the better painting). Thurstone also argued that this approach could be a better approach to assessment (Thurstone, 1927).

With the improvement of technology and the emergence of mathematical models for educational tests (Rasch, 1960), Thurstone's work was improved upon by enhancing the comparative judgment process with the supplementation of technology (Pollitt & Murray, 1996). These improvements allowed individuals to proceed through a series of comparative judgments using technology tools, while simultaneously recording and analyzing the data for analysis. The analyzed data was then utilized to produce a rank order of all included items as well as a relative quality score for each item called a parameter value. Parameter values are calculated based on the win/loss record of each item used to produce the rank order (Pollitt & Whitehouse, 2012). The work around CJ was furthered through the addition of an algorithm, which introduced the adaptive element of

adaptive comparative judgments. This adaptivity allowed for the system to selectively pair the work being assessed by judges based on the win-loss record of each item. A plethora of research related to ACJ has been undertaken (Bartholomew & Yoshikawa, 2018, Kimbell, 2012a, 2012b; Pollitt, 2012) which has consistently demonstrated potential for reliable and valid results.

In addition to the results produced through ACJ processes another byproduct, collected through ACJ technologies such as CompareAssess, is the judge comments related to each decision. As judges make comparative judgments their rationale for their decision can be collected, in the form of typed comments, which can be used for later analysis and exploration. These comments may prove valuable in relation to CBE assessment to determine the rationale behind identified competence while engaging in ACJ.

#### **4. METHODOLOGY**

This exploratory effort involved multiple studies across four different disciplines related to design and technology. Each of these exploratory efforts utilized a different approach to CBE assessment which incorporated ACJ (see Table 1). In each case no changes were made to any of the course instructions or assignment, and in every study students participated in an ACJ session at some point during their course.

##### ***4.1 Transdisciplinary Studies in Technology (TST)***

In TST, one section consisting of 28 students (N=28) participated in the study along with two participating instructors. Each student produced an Audio Visual (AV) communications project and a design thinking (DT) project that were assessed by their instructors using ACJ. Following the ACJ sessions, the rank orders were collected and the instructors for the course were asked to independently use the rank order and draw a “cut-off” line above which student projects demonstrated competence and below which they did not. Further the instructors also assessed all student work, for both the AV and DT projects, using traditional rubric-centered approaches for CBE current in place at the university. Comparisons between rank orders produced by each group and weighted Kappa values for CBE cut-offs were computed to investigate implications for CBE assessment.

##### ***4.2 Theater (THTR)***

Sixteen students (N=16) enrolled in an introductory course studying audio technology were included in this project. The participating instructor provided 18 audio files from three different genres (e.g. pop, orchestral, and spoken) that were included in three ACJ sessions to be used as an assessment of student understanding of reverberation theory and quality. The students participated in the three ACJ sessions, choosing the audio file which demonstrated the better reverberation effect from each comparative pairing. The rank order produced from the three ACJ sessions was compared with industry-accepted standards for and practices for reverberation. Further, to investigate the potential for CBE evaluation, the individual comparative choices made by students were compared with the industry-accepted standards for included files.

##### ***4.3 Interior Design (ID)***

Four faculty and four practicing interior designers participated as judges in an ACJ session with student portfolios. Student’s portfolios consisted of work from a variety of classes and were submitted with the intent of admittance into the Interior Design degree program at the University. Prior to the ACJ session the participating faculty determined that they would use the ACJ-produced rank order to identify 25-26 students for admittance into the program based on competency demonstrated. The participating judges used the resulting rank order to identify a “cut-off” point below which student work was not acceptable which was used to determine admittance into the degree program.

##### ***4.4 Computer Graphic Technology (CGT)***

Students (N = 36) enrolled in a computer game development course completed six individual projects and one group project (the final assignment). For each assignment students produced a short video demonstration of their product “in action” - each of these videos was used in an ACJ session created for each assignment in which all students and the instructors participated. For the final projects only the instructors participated in the

ACJ session containing student final projects. Additionally, all final projects were presented to a panel of industry professionals (N = 17) who ranked the work. Both industry professionals and the instructors used the rank orders produced to draw a “cut-off” for student projects which demonstrated projects. Similarities, differences, and potential for CBE evaluation through ACJ were explored with the associated results.

#### 4.5 Engineering Education (ENE)

Students (N = 111) worked in groups (N = 29) to document their work on an industry-provided design challenge related to an innovative wastebasket. Student’s portfolios were included in three separate ACJ sessions. Sessions were completed by the students, the instructors, and industry professionals. The resulting rank orders, obtained from each session, were compared and similarities and differences were identified.

Table 1. Study Overview

Course	Course Objective	Artifact	CBE Approach
Transdisciplinary Studies in Technology (TST)	Competency-based education course for students interested in business, humanities, and technology	A/V: portfolio documenting competence in visual and audio design  Design Thinking: portfolio documenting competence in design thinking	ACJ assessment by instructors which resulted in a rank order of student work. Instructors (independently) identified the competency cut-off within the rank Weighted Kappa agreement testing between instructors for competency cut-off
Introduction to Audio Technology (THTR)	Introductory class focusing on audio theory, techniques, and evaluation	Audio files exhibiting different reverberation qualities	ACJ assessment by students to determine a rank of audio files by reverberation quality. Comparison of rank (produced by the students together and individually) with industry-accepted standards to determine competence in audio reverberation exercises
Introduction to Interior Design (ID)	Portfolio Review for all students wanting to be accepted into the program	Interior design portfolio with specified assignment submissions. Included artifacts from specific art and design classes as well as introduction to interior design classes.	ACJ assessment by eight reviewers. The reviewers consisted of ID faculty as well as professionals in the field. After student work had been ranked, the ID faculty met to identify a cutoff in the rank for student acceptance into the program.
Simulation and Gaming (CGT)	Introduction to computer game development, processes, and technology	Screen capture videos of student-created video games	ACJ assessment by instructors and students which resulted in two rank orders of student work. Student work, presented to industry professionals, was ranked and a competency cut-off was determined. These results were compared with the student and teacher-produced ACJ ranks.
Introduction to Engineering Design (ENE)	Introductory course for all engineering disciplines	Student design portfolios for an industry-sponsored design challenge around creating a new wastebasket	ACJ assessment of student design portfolios by instructors, students, and industry professionals. Resulted in three rank orders of student work. Comparison of rank orders produced by each group and identification of similarities and differences

Following each of the described studies the associated data was recorded, conditioned, and analyzed using statistical software (SPSS 24). The resulting findings, potential implications, and possibilities for CBE assessment will be discussed below.

## 5. RESULTS

The findings, derived from each of the exploratory projects outlined above, will be discussed in turn. Implications and possibilities for CBE assessment will be also be briefly discussed.

### 5.1 TST

Weighted Kappa agreement testing for the cut-off locations, produced independently by the instructors on the rank order of student work, demonstrated moderate agreement ( $\kappa = .54$ ) for the design thinking competency cut-off and fair agreement ( $\kappa = .31$ ) for the AV competency cut-off. Similar results were obtained in additional confirmatory testing through nominal-scaled codes and Cronbach's Kappa. These agreement findings suggest that using the ACJ-produced rank to identify a cut-off for student competencies may be a valid approach but, additional studies, which could potentially result in higher levels of agreement between instructors, would lend additional credence to this approach.

### 5.2 THTR

When compared with industry standards the student-produced rank order of audio files was significantly correlated for the pop music session ( $r_s = .94$ ), the spoken word session ( $r_s = .97$ ), but not for the orchestra audio session ( $r_s = .20$ ). Additional testing for each student individually showed that the majority of students were highly accurate at choosing the better audio file during the comparative judgments for both the pop and spoken word sessions. However, almost all the students struggled in the orchestra audio session to identify better quality during the comparisons. These findings suggest that ACJ may be a useful tool for understanding student competence in relation to specific areas of education; specifically, students demonstrated great aptitude in identifying subtle differences in quality for two the audio ACJ sessions which may demonstrate competence in that particular skill area.

### 5.3 ID

The rank order, and the associated parameter values, were used to plot the results of the ACJ session (see Figure 1). A noticeable “drop” was evident before and after the 26th –ranked item in the list which resulted in the faculty assigning the competency cut-off immediately following the 25th –ranked product (see Figure 2). This cut-off, which the faculty regarded as a competency measurement, was used to determine admission into the program for potential students.

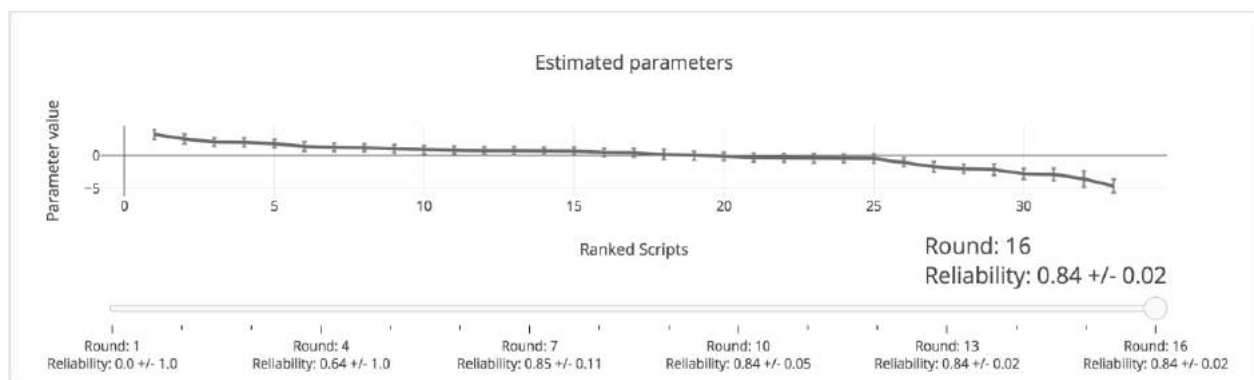


Figure 1. Rank order produced during the ACJ session for interior design portfolio review

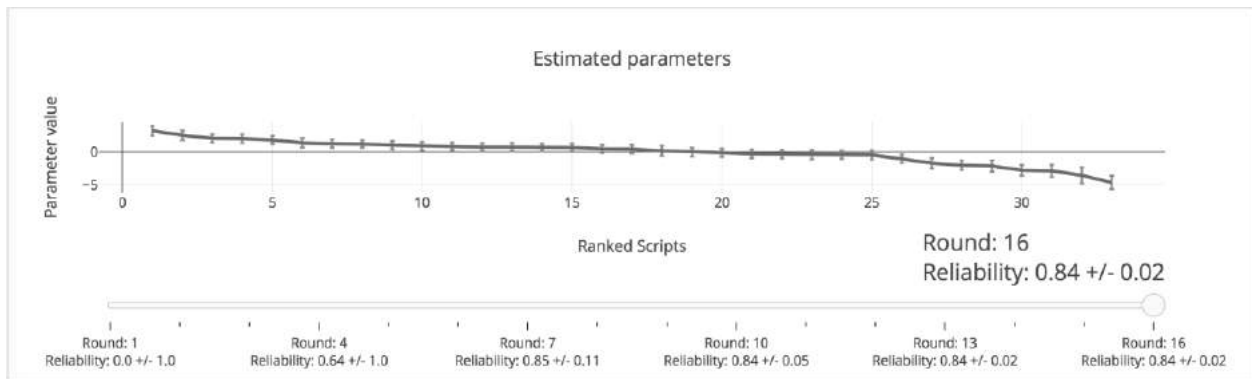


Figure 2. Drop off in parameter values of student portfolios chosen as the cut-off for student acceptance into the interior design program

#### 5.4 CGT

While the Spearman correlational tests revealed significant correlations between the instructor-produced and student-produced ACJ ranks for several of the projects (e.g.,  $r = .798$ ,  $p < .001$  for project 4, and  $r = .719$ ,  $p < .001$  for project 5) there were disparities between the industry professionals and the other ranks produced by students and instructors.

All industry cut-off values were recorded and recoded as 1 (competent) or 0 (not competent). Following this recoding an average score for each student item was obtained and a point-biserial correlation between the instructor-produced ACJ rank and the industry-produced cut-off was calculated. The results were not significant ( $r_{bs} = -.372$ ) suggesting that the ACJ-produced rank order from the instructors and the competency cut-offs, identified by the industry professionals, were not necessarily aligned.

However, there is potential in utilizing the industry-produced cut-offs as there were several portfolios which were almost unanimously identified as “competent” and several others were almost unanimously identified as “not competent” by the industry judges. For example, Team 9 was identified as “competent” by 16/17 industry judges while only 4/17 industry professionals identified Team 12 as “competent.” Thus, this approach to using ACJ for CBE assessment by industry professionals may be a feasible approach to assessment of competencies required for success in industry.

#### 5.5 ENE

A Spearman correlation between the final rank-order of student work produced by the instructors, students, and practicing engineers indicated significant correlations between the ranks produced by students and instructors ( $r_s = .56$ ,  $p < .001$ ) and the ranks produced by students and practicing engineers ( $r_s = .66$ ,  $p < .001$ ). However, the correlation between the ranks for student work produced by practicing engineers and instructors was not significant ( $r = .33$ ,  $p = .08$ ). These findings indicated potential discrepancies between the assessment of competencies between three included groups. To further illustrate, and investigate these differences, we graphed the ranks for each group portfolio, to demonstrate the similarities and differences in group rankings (see Figure 3). The differences in rankings suggest some difficulty in assessing competencies with this approach if the intent was designed towards agreement between groups. For example, the rankings for Group 6’s portfolio indicate relative agreement between the three groups of judges while Group 14’s portfolios shows close alignment between the students and instructors but a large disparity with the industry-produced rank.

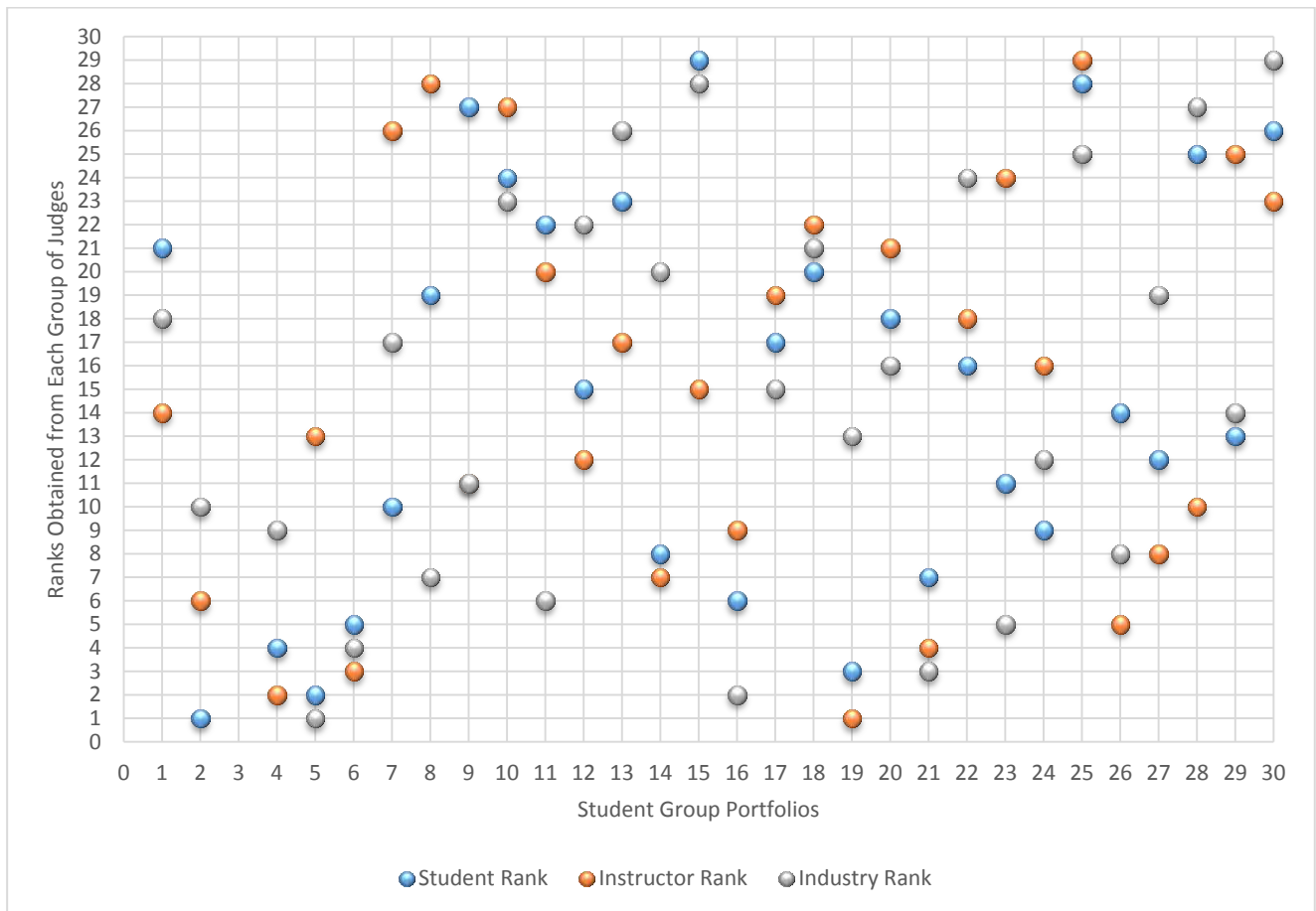


Figure 3. Overall Rankings for Student Portfolios by Students, Instructors, and Practicing Engineers

## 6. DISCUSSION

Our research objective of exploring the potential for identifying student competencies in design and technical education through adaptive comparative judgment led to a variety of different implementations. The findings from each of the studies outlined indicate that ACJ may be a promising tool for the assessment of student competencies in, and outside of, competency-based educational settings. However, it is important to note that before ACJ could be successfully utilized in CBE assessment the definition, and associated criteria, of “competency” should be clearly defined. Answers to questions around who gets to decide what “competent” is, how it may be represented, and to what end all need answers for real progress in CBE assessment. For example, is a student “competent” if industry professionals deem them “on-track” for success? Is a student “competent” if they can correctly choose “better” items when making pairwise comparisons? Is a student “competent” if they fall above a threshold determined using a rank-ordering of student work? These questions, and potentially many more, all need answered before widespread use of ACJ can be realized as a tool for CBE.

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# Implications of the Learning Sciences for the Unique Intent and Remit of Technology Education

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This paper utilises the distinction between the activity of learning (acquiring of knowledge) and the resultant outcome of learning (acquired knowledge) to discuss the nature of learning espoused in technology education. Reference is made to the significant body of research which has accumulated from the field of learning sciences and the potential benefits and limitations applicability of such a perspective to informing practice in technology education. Cognitive load theory has garnered a significant body of research which has been empirically verified to improve the quality of instructional design although the benefit of such research has yet to be determined in the acquisition of technological knowledge. The concepts of biologically primary and biologically secondary knowledge are used to facilitate the categorisation of technological knowledge as lending itself to both and the implications of such a categorisation are discussed. A synthesis of these perspectives highlights the irreconcilable agenda of defining an exclusive knowledge base of technology education although the applicability of cognitive load theory to inform instructional practice in technology education is proposed. The paper also concludes with the assertion that investigating the nature of cognitive load theory in the context of acquiring technological knowledge has the potential to further understanding of learning in technology education.

*Key Words: Learning science, technology education, biologically primary and secondary knowledge.*

## 1. INTRODUCTION

The challenge of any formal education system is the appropriation and development of knowledge. Snedden (1921) put forward the argument that the structure of any educational curriculum must be justified by its benefit to society and the distinction between subjects is premised on the fragmentation of knowledge deemed to be independently and collectively of value. With this premise, the significance of articulating the benefit of technology education to society on the basis of the utility of the knowledge it espouses to develop, this is paramount given the constant scrutiny directed towards the discipline. Such an endeavour has previously been met with difficulty when comparing Technology to others such as mathematics and science education which have clearly defined boundaries of content knowledge. The distinction of what can and cannot be learned needs to be explicit and inform the remit and intent of the educational agenda. This would then give a means for pupils' inherent capacities to be explicitly appropriated so as to accommodate the explicit developmental intent of any designed activity. This poses a relevant but currently irreconcilable problem in the epistemological underpinnings of technology education which explicitly advocates for the development of problem solving skills. It also highlights the distinctly unique nature of technology education as a part of a holistic education. The 'practice' of education as stated here is primarily addressing the interaction between the learning of the pupil and the teaching of the teacher. The distinction between what technological education aims to develop and what can be developed through instruction is therefore critical to establish and guide pedagogical practice.



## 2. COGNITION AND LEARNING

In 1976 Ulric Neisser defined cognition as “the activity of knowing: the acquisition, organisation, and use of knowledge” (1976, p. 1). A significant body of empirical evidence has since manifested which concurs with this premise and has ultimately aligned with a goal of cognitive psychology to “help people use cognition in real-life situations” (Sternberg & Sternberg, 2009). One outcome of this has been the development in understanding of how people learn. As a result, acknowledgment of the importance of considering cognitive architecture when designing instructional methods for pupil learning has grown and with it the investment in approaches to understand how people learn and why there are differences in the success of learners. The learning sciences have yielded the most specific of findings to inform understandings of how people acquire knowledge. Much of this research is predicated on the principles and findings of cognitive science research and has increased the applicability of such research to the classroom, bridging the gap between an understanding of cognition and the utility of such an understanding for practice. The effectiveness of this approach to educational research is evident in the rigorous means by which it has debunked practices previously believed to be essential to learning like growth mindset (Bahník & Vranka, 2017; Li & Bates, 2017; Macnamara & Rupani, 2017) and preferential learning styles (Kirschner, 2017; Knoll, Otani, Skeel, & Van Horn, 2017). Research in the learning sciences is therefore qualified by the potential for practical impact, highlighting its intent to develop the evidence base that can inform practice by furthering understandings of phenomena influential to learning (Nathan & Wagner Alibali, 2010).

Distinctions between what learning is and how learning happens are important from the perspective of instructional design, which is arguably the facet of educational practice which should be informed most directly by findings from learning sciences research. Clarity of what the result of learning is, is important to consider when critiquing how learning manifests as an activity. Defining learning as “a change in long-term memory” (Kirschner, Sweller, & Clark, 2006) highlights the inseparable relationship between learning and memory - where learning occurs when acquiring knowledge and learning has occurred when that knowledge has been committed to memory (Neath, 2000). Therefore, consideration of cognitive architecture when describing the activity and goal of learning is essential. Working memory and long-term memory relate to the acquiring and storing of knowledge respectively. Working memory is limited in its capacity to process information and the length of time it can hold this information (Cowan, 2001) whereas long term memory is essentially a limitless store of information (Paas & Sweller, 2012; Sweller, 2010a; Sweller, van Merriënboer, & Paas, 1998). The efficiency by which people acquire knowledge is therefore dependent upon the appropriateness of the prescribed information to be learned and their working memory capacity so that change in long-term memory relevant to the intended learning can manifest.

Cognitive Load Theory (Sweller, 1994) was first proposed as a response to evidence that extraneous mental effort induced by learning tasks has a negative effect on learning (Sweller, 1988; Sweller & Chandler, 1991). Since its inception as a useful consideration in instructional design significant research has been conducted to highlight aspects of instruction which induce unnecessary cognitive load and therefore reduce the efficacy by which information can be learned (extraneous cognitive load). This research has been premised on the importance of understanding how people learn elements of knowledge when design instructional tasks. Element interactivity has a significant impact on the extent of cognitive load induced. When the information to be learned has high interactivity with already learned knowledge the cognitive load induced by the task will be lower than if the element of information has low interactivity with already acquired knowledge (Sweller & Chandler, 1994). Element interactivity with reference to intrinsic (cognitive load induced by what is essential to the task) and extraneous cognitive load (the result of unnecessary instructional practice), demonstrates the interplay of prescribed knowledge and the means of acquiring such knowledge that must be considered in instructional design (Sweller, 2010b). A systematic review of the research by Schneider and Preckel (2017) provides evidence that the most significant student variables associated with achievement in higher education are intelligence and prior knowledge. The significance of prior knowledge in determining successful learning concurs with research highlighting the role of prior knowledge in the acquisition of new knowledge (Hambrick, 2003).

### 3. KNOWLEDGE AND LEARNING

The distinction between technology education and other areas of education is made with regard to the type of knowledge that is prescribed (Buckley, Seery, Power, & Phelan, 2018; de Vries, 2005) and the nature of the activity through which this knowledge is acquired (Kimbell & Stables, 2007). This again speaks to the important distinction between what is the intended result and modality of learning in the discipline, particularly when discussing the applicability of findings relating to the acquisition of knowledge, and specifically the acquisition of technological knowledge. The capacity to acquire such knowledge has been acknowledged to be one of the most significant traits in establishing homo sapiens' dominance (Pinker, 2010; Tooby & DeVore, 1987). Given the human capacity to acquire this form of knowledge, distinction between knowledge types that are acquired naturally and due to cultural necessity presents a useful lens through which to view the nature of learning in technology education.

The categorisation of knowledge into biologically primary and biologically secondary knowledge was first introduced from an evolutionary educational psychology perspective (Geary, 2002). This dichotomy has been advocated for as an important distinction between knowledge types when rationalising what can be taught and learned through instruction (Paas & Sweller, 2012; Sweller, 2010a). Biologically primary knowledge is knowledge people have evolved to acquire and is "learnable but not teachable" (Sweller, 2010a, p. 4). The acquisition of biologically primary knowledge is dependent on "inherent cognitive systems and child-initiated activities" (Geary, 2002, p. 328) and not on systemic educational instruction as such activity is responsible for the development of biologically secondary knowledge. Biologically secondary knowledge is "learnable and teachable" (Sweller, 2010a, p. 4). Selection of what biologically secondary knowledge is worth learning is determined by what is deemed to have cultural significance and cannot be learned in isolation of the conscious effort of the learner e.g. learning to use a computer. This aligns with the position of Snedden (1921) as biologically secondary knowledge cannot be developed independent of instruction and therefore is beneficial to develop in formal education. An explanation of the difference in effort required of pupils to acquire biologically secondary knowledge such as the ability to read and write and biologically primary knowledge such as the ability to speak is made clear through this distinction. Generally, biologically primary knowledge is developed tacitly and independent of instruction. Furthermore, it is argued that the inclusion of biologically primary knowledge in curricula adds redundancy as developing this type of knowledge does not depend on educational intervention (Paas & Sweller, 2012).

For example, learning how to open a milk carton is a biologically secondary skill that we have not specifically evolved to acquire. In contrast, showing someone how to manipulate an object to reach a goal such as opening a milk carton may be biologically primary. The act of demonstrating physical manipulation is a complex act but we do not need to make it part of any formal curriculum because we engage in that natural pedagogy automatically. (Paas & Sweller, 2012, p. 40)

Paas and Sweller (2012) do however highlight the importance of acknowledging the role of biologically primary knowledge in the acquisition of biologically secondary knowledge. The minimal effort required to acquire primary knowledge can be used to augment the efficiency of acquiring secondary knowledge. This relates to the lower demands imposed on working memory when acquiring primary knowledge. Paas and Sweller (2012) use this differentiation of load induced when acquiring primary and secondary knowledge to posit an explanation as to why dual coding during instruction (the use of visual and auditory stimuli together) reduces cognitive load. The natural capacity of people to develop grammatical language (for first learned languages) is dependent on a biologically primary skill (Pinker, 2010; Tooby & DeVore, 1987). Therefore, accompanying the visual stimulus with spoken language can augment the learner's capacity to acquire the knowledge being taught due to the biologically primary ability to more efficiently encode linguistic information. Therefore, reduced extraneous cognitive load induced by the reduced working memory resources needed to process the linguistically communicated information leaves more resources free to process the intrinsic cognitive load associated with the information being taught. From this perspective it may be useful to premise that one mechanism underpinning the design of instructional tasks should be the augmentation of the acquisition of biologically secondary knowledge through the inherent human nature to process biologically primary knowledge (Paas & Sweller, 2012).

#### 4. PRIMARY AND SECONDARY KNOWLEDGE IN TECHNOLOGY EDUCATION

Given the substantive body of evidence afforded from the learning sciences research and more specifically the principles of cognitive load theory, considering the potential utility of this research to inform instructional practice in technology education is essential. Although, the applicability of these findings in this context is difficult to clarify in a subject that is essentially dynamical to the learners' acquisition and application of context specific knowledge while also intent on developing technological knowledge. Kimbell and Stables state that in Design and Technology "knowledge and skills should be **sought out** by learners rather than **force-fed** by teachers" (2007, p. 38). This compliments the view that some technological knowledge cannot be expressed in propositions and must be acquired differently to knowledge which can be expressed in such forms (de Vries, 2005; Norman & Baynes, 2017), alluding to the fluid nature of the epistemology of design (Norman, 2013) and technology. Although, such autonomous activity in a learning transaction is discouraged in cognitive load literature as it is deemed to be inefficient in the learners' acquisition of the relevant knowledge. This problematises the means by which cognitive load theory can inform practice in technology education. Subsequently, the applicability of findings from the learning sciences to practice in technology education directly may not be appropriate as the modality of learning appropriated in the disciplines within which the learning science research was conducted may not align with the epistemological basis for knowledge and skill acquisition in technology education as highlighted above.

The definition of biological primary knowledge as knowledge that can be learned and not taught is argued to introduce redundancies in educational practice in subjects such as Science and Mathematics which have a defined content base of prescribed biologically secondary knowledge. Although, given the unique evolutionary capacity of people to acquire technological knowledge, excluding the potential of developing biological primary knowledge in technology education may be detrimental. Especially when the alternative is substituting it for a more biologically secondary knowledge, laden provision. Generic skills are defined as biologically primary knowledge. Generic problem-solving skills are therefore biologically primary as people acquire these skills naturally from experience. The enactment of these generic problem solving skills in technology education is predicated on developing the learner's ability to deal with uncertainty (Kimbell & Stables, 2007) by developing the learners' capacity to direct the acquisition of knowledge appropriate to the task. Therefore, the capacity of the learner to direct the inherently biologically primary capacity to solve problems is intended to be developed. This potentiates the conception of technology education as developing the disposition of a more refined problem solver by facilitating the development of this biologically primary capacity for utility in dealing with ill-structured technological problems. This poses some difficulty when categorising technological activity as developing biologically primary or biologically secondary knowledge. The capacity to acquire technological knowledge independent of knowing the underpinning rules which govern its application is evolutionarily dependent (Pinker, 2010; Tooby & DeVore, 1987). Referring to technological knowledge as involving the application of secondary knowledge dependent on governance by primary knowledge concurs with the suggestion by Paas and Sweller "that many skills may consist of a combination of primary and secondary knowledge and so we may be dealing more with a continuum than a dichotomy" (2012, p. 40).

Kimbell's (1994) distinction between closed and open tasks as having varying degrees of permeability in affordance of pupil autonomy is worthy of note as it describes a continuum of learning in technology education which aligns with the continuum of primary and secondary knowledge. Closed tasks impose greater limits on the learners' autonomy and as a consequence are prescribed to novice learners in the discipline. At this closed end of the continuum the nature of the task is predicated on the acquisition of prescribed knowledge and requires greater guidance from the teacher on the application of this newly acquired knowledge. Furthermore, the knowledge being acquired as a result of instruction is biologically secondary as it has relevance to the nature of future activity e.g. procedural knowledge, health and safety considerations or standards of best practice. As learners progress they traverse the continuum to more open tasks where their autonomy has a greater effect on the direction taken in the task. Their experience of the tasks may facilitate the development of biologically primary knowledge due to the nature of the instruction provided by the teacher being less prescriptive of knowledge and more active in "directing the pupil into areas that she judges will be useful for the pupil to experience" (Kimbell, 1994, p. 243). Such a progression highlights the nature of technology as a "somewhat amorphous activity rather than a distinct discipline" (Kimbell, 1994, p. 242).

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# Speculative Writing: Enabling Design Thinking

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Writing, with its unique capacity to describe the essential, yet elusive relationship between creation and context, may be the most important skill in design. Speculative writing, in particular, is emerging as a valuable means of eliciting creative, critical design thinking and writing, with significant and increasing numbers of speculative writing subjects recently developed for design-focused higher education degree programs. These courses employ a plethora of pedagogical approaches to creative writing practice, enabling students to engage in design thinking about future contexts, and create what are known as design fictions (Blythe, 2014; Dunne & Raby, 2013, p. 2) or design ‘futuring’ (Fry, 2009). The practice of speculative writing can be both creative and critical, and evolving forms – including creative non-fiction (Tansley & Maftai, 2015), critical speculation, and quasi-fiction – blend fact and fiction, research and speculation. The resulting works are research-informed, with the potential to be paradigm disrupting narratives (Inayatullah, 2008). In particular, speculative writing within design practice has been shown to enable critical thinking around sustainable consequences of design including ecological, social, and economic factors. The methodology thus epitomises Design and Technologies’ educational aim of imagining sustainable global futures (Stables & Keirl, 2015). This paper will illustrate the philosophy and usage of speculative writing, outline current literature and discuss a case study approach to speculative writing used in Design education. It will consider how these valuable narrative methodologies – recurrently used in both primary school curricula and tertiary Design courses – might be implemented by Design and Technology educators at secondary level, and pose the question: Could these practices, which blend creative and critical thinking, also be harnessed to the benefit of Design and Technology education?

*Key Words: Speculative writing, Creative thinking, Critical thinking, Design thinking.*

## 1. WHY SPECULATIVE WRITING?

Speculative writing, when used as a learning and teaching tool in the design context, can enable forms of creative and critical contemplation, cultivating imagination, innovation and transformation for future-focused design thinking. Valkenburn and Kleinsmann (2016) outline four types of innovative design thinking: value-driven, experience driven, purpose-driven and vision-driven. “Vision-driven innovators,” they write, “see a world in which the far future is uncertain and unknown.” In rapidly changing times, they consider such thinkers able to “develop a sensitivity towards what is a meaningful and sustainable direction” (Valkenburg & Kleinsmann, 2016). And it is this ‘vision-driven design thinking’ that scaffolded speculative writing promotes. As Greenstein explains, writing enables speculative thinking because writing enables us to think (Greenstein, 2013). By giving form and process to imagination and creativity, design writing allows innovation and speculation to emerge. Speculative writing is a form of design thinking ‘in action’, enabling a more vivid, specific and nuanced context to be defined. It enables a designer to ask more probing questions of the essential problem and articulate more specific answers.

Speculative thinking is also being used in design more broadly to encompass sustainability impacts beyond our known, local spheres (Acaroglu, 2014a). The design provocation might be, for example, an ecological crisis which significantly alters the needs, wants, and values of the end-user (Acaroglu, 2014b). In addition, speculative thinking is being used to develop ‘disruptive design’ strategies, enhancing systems thinking in design (Acaroglu, 2017), human centred design (IDEO, 2018), situated design (Simonsen, 2014), and embodied design methods (Malinin, 2016). Valkenburn and Kleinsmann describe how vision driven innovation relies upon speculative thinking, writing, and making to help “create visions for the future and ... provoke dialogue and discussion” (2016). Speculative writing and critical discussion is, therefore, being used by futurists to

create imaginative narratives – the first stage of a creative, imaginative research practice in a cyclical speculative design methodology.

### ***1.1. Speculative writing in Design and Technology Education***

Design and Technology education programs ask educators to focus on developing creative and critical thinking, aims summarised by the Australian Curriculum and Reporting Authority (ACARA) in the Australian National Curriculum for Technologies, suggesting students learn to: “think critically and creatively about possible, probable and preferred futures”. This highlights the need for students to imagine and articulate future scenarios. Speculative thinking and writing methods are already embedded in higher education design programs, especially at post-graduate level, and in areas of commercial design through design futuring (Fry, 2009). However, as part of a creative and critical thinking pedagogy in Design and Technology education, their capacity to enable design innovation is still underutilised.

For Design and Technology education, speculative writing can become part of a design process. Designer educators Dunne and Raby, for example, develop speculative narratives, objects and scenarios in a cyclic process of thinking, writing, making, enabling engagement, dialogue, and reflection to occur (2013). The Near Future Laboratory work in similar way, where designers collaboratively develop a design brief, posing questions which “represent the answers as design fictional services, evolutions of product categories and new kinds of social, domestic and retail experiences”, then creating physical speculative products for the TBD Catalog, an illustrated “catalog for your normal ordinary everyday near future” (Near-Future-Laboratory)<sup>2</sup>. A combination of such tools can be used in Design and Technology education, cycling through speculative thinking, writing, making, and reflection.

### ***1.2. Design Thinking Competency***

Writing as a core competency in design education is contentious. Design students largely want to make things, and do not wish to linger on the preliminary conceptual processes essential to the design of worthy items. Martin and Owen-Jackson (2013) described key aspects of this debate, asking “Is design and technology about making or knowing?” (2013, p. 64), and discussing the erroneous perception that “less academic pupils are more suited to practical subjects than their academic peers” (Martin & Owen-Jackson, 2013, p. 65). Martin & Owen-Jackson also outline a dichotomy between what students are required to know and what they are tested on (2013) that is prevalent in many Design and Technology programs. Ideally, assessment weighting should balance prototype, documentation, design folio and theoretical components. In many programs, however, the assessment value of the design folio, documentation and written exams outweighs the value of the physical prototype. Yet ‘writing’ as a practice is seen by students as competing with ‘making’. Whilst this dichotomy still exists, speculative writing can provide an engaging creative provocation for writing and support design development relating to preferred futures thinking. By doing so, it can assist students when it is necessary to conceptually, imaginatively situate their design thinking and convey an experiential understanding of needs and values that sit outside their own personal experience. Martin and Owen-Jackson (2013), Baynes (2010) and Norman (Coles & Norman, 2005) offer insights into why writing cannot easily communicate a students’ tacit knowledge, designerly literacy or insights and describe some of the issues related to contemporary epistemological views of Design and Technology education. However, the capacity of speculative writing as a design augmentation tool able to populate a speculative design-scenario offers an alternative angle. As design provocateur, speculative writing can be the catalyst for focused, critical design thinking, making, and reflective practice. It opens up new possibilities: potentially delivering solutions to design problems that may not otherwise have been imagined or articulated, and, crucially to imagine, to think and write beyond assumptions and what is already known.

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<sup>2</sup> Near Future Laboratory: TBD Catalog, A Catalog for your Normal Ordinary Everyday Near Future  
<http://tbdcatalog.com/>

An overview of the design thinking, and collaborative process is available here <https://vimeo.com/107015105>

An educational tool for design students developed by the Near Future Laboratory: Design Fiction Product Design Work Kit 0-TBD-D012 <https://shop.nearfuturelaboratory.com/products/design-fiction-product-design-work-kit>

### ***1.3. Context: story-telling practices in design, sociology, anthropology and pedagogy***

Speculative writing provides the opportunity for story-telling and design to work in tandem. The use of design narrative is well-established in industrial and product design but is far less utilised in education. However, many design-theorists are reiterating the role of story-telling in design and considering how it might propel innovation, like Beckman and Barry (2009). Dunne and Raby (2013) suggest that creative ‘design fictions’ are the way to inhabit ideas and enable speculative thinking. Sociology theory (Hoskins, 2006) broadly suggests that when we obtain an object, we are really purchasing or engaging with its ‘story’ – the connotative associations, rather than the object itself. An item’s perceived value and cultural status, therefore, is intrinsically linked to its narrative (Woodward, 2007). Extending this idea, Hoskins describes how designerly objects are imbued with personal agency and engender a sense of biography: and ‘tell the stories of people’s lives’ (Hoskins, 2013, p. 2). This sense of agency is reiterated within an educational context by Moon (2010, p. vii), who has defined “the role of story-telling in higher education”. Overviews of a comprehensive range of multi-discipline examples (from science, the arts and humanities), Moon (2010) offers a useful variety of approaches for active story-telling as a pedagogical device in education<sup>3</sup> and the theoretical concepts which inform them<sup>4</sup>. Her research focuses on writing in education, reflective writing (2004), creative writing strategies (2010) and critical thinking (2008), and supplies useful pedagogical strategies (Moon, 2004, 2008, 2010). Anthropologists, too, describe the need to re-envision design practices in response to creativity and cultural improvisation (Grimshaw & Ravetz, 2005; Hallam & Ingold, 2007). Ingold asks us to reframe our response to materiality, and link creative, critical and speculative design thinking including a ‘textility of making’ (Ingold, 2010b), ‘designing and environmental relations’ (Anusas & Ingold, 2013). ‘Reading forward’ in terms of creative thinking is encouraged, and an ideal ‘improvisational and generative approach’ is described (Ingold, 2010a). Such methodologies, strategies and theories inform and enrich speculative thinking and clarify its role as generative design tool. It is this diversity of approach that links the creative and critical faculties, enabling the true innovation required if we are to prepare students to address altogether new global challenges.

## **2. RESEARCH METHODOLOGY**

The research delineated in the case study below was completed using an action research methodology (McAteer, 2013; McNiff & Whitehead, 2005) and active participant observer stance (Klein, 2012). A grounded theory, qualitative methodology was used – whereby the researcher attempts to observe and gather data without preconceptions using open-ended research questions to develop new insights (Bryant, 2017). The researcher used inductive reasoning to develop a set of theoretical precepts revealed through analysis. The research questions were: (a) How has this speculative writing task been scaffolded and why? (b) How does this particular scaffold, which includes a variety of small components and short pieces of writing, enable visually focused design students to engage with a conceptual speculative writing task? This research methodology takes into account the experience and ‘theoretical sensitivity’ (Bryant, 2017) of the researcher, in relation to the design of creative writing scaffolds for enhancing design thinking for higher-education students<sup>5</sup>.

### ***2.1. Case Study: Speculative Writing in Undergraduate Design***

Speculative writing was used with undergraduate design students as preliminary conceptual design research. Students completed three concise narratives: a research-based future report, a speculative future scenario context statement, and a speculative user-profile based on the future scenario.

#### ***2.1.1. Aim***

To investigate the use of speculative writing to engage students’ creative and critical analytical faculties, and activate their capacity to encompass design requirements.

#### ***2.1.2. Hypothesis***

Completing a series of short research-based narratives will enable students to determine, engage with, and respond to a specific set of speculative design constraints, prior to undertaking a comprehensive design project.

<sup>3</sup> See (Moon, 2010), Part III Story in Higher Education and Professional Development: A treasury of ideas, pp. 99-168.

<sup>4</sup> See (Moon, 2010), Part II Theory: Story and Human Functioning, pp. 31-98.

<sup>5</sup> The researcher/educator has ten years of experience developing creative skills in design with undergraduate and post-graduate students in higher education.



### 2.1.3. Method

Students undertook a research-informed design process using speculative design fictions (Blythe, 2014). The final design task was to: design a collection of fashion items and futuristic textiles with ‘extreme’ or ‘maverick’ properties in response to a speculative future context and persona.

As preliminary tasks, students were instructed to:

- Research post-apocalyptic film and literature examples and undertake simple psychological character analysis;
- develop a photographic image sequence (visually indicating a hypothetical context); and
- construct speculative objects (DAB). Due to the fashion context these were body-props (Andersen & Wilde, 2010) or “critical and speculative wearables” (Flanagan, 2017).

Following these preliminary tasks, students were guided to complete three short, discrete pieces of speculative writing, as outlined below.

- a) Future Report (800 words). A forecasting report addressing future developments in technology, science, culture, communication, transport, lifestyle, cities, attitudes, values and culture more broadly.
- b) Future Scenario (300 words). A descriptive narrative describing the above future society and context. Rather than predicting, students speculate and imagine.
- c) Persona (600 words). A persona is an imaginative, rich, detailed description of a person who will live in the previously-described future society. Name, age, occupation, biographical information, personal history, emotional life, attitudes, specific goals, aspirations, needs, tastes and aesthetics, relationships and idiosyncrasies should all be covered. This must be a “believable, living, written portrait of a person” (Robinson, 2017).

This speculative writing design methodology included critical design provocations, exploring what Kjærsgaard and Boer describe as “the speculative and the mundane in practices of future-making-exploring relations between design anthropology and critical design” (2015, p. 1). Thus, students are able to experience the relationship between creative, critical thinking in design and what can be learned in design through an anthropological approach.

## 2.2. Research observations and discussion

### 2.2.1. Conceptual scaffolding

During their initial research works, students were asked to consider a catalyst like an environmental catastrophe rendering parts of the world uninhabitable, the acceleration of a specific ecological issue like a shortage of bees, or an anti-technology advocacy group determined to live off-grid. This leveraged references from dystopian literature and film and proved to serve several important purposes: students had a complex aesthetic rendering of an alternative earth scenarios; they gained a sense of how narratives evolve in response to complex circumstances; and developed an understanding of how values and a society’s morality shifts in response to scarcity or fear. These contextual aids also provided a sense of individual characters, as students were required to look forwards and backwards to consider how the needs, wants, values and hopes of that individual were framed by their situation.

### 2.2.2. Process challenges

Students gradually focused on evolving relatively complex short pieces of writing despite the modest word counts. Some students found it difficult to comply with the word counts and almost all underestimated the amount of research, level of refinement, or synthesis of ideas required to convey concepts concisely. Workshops focused on supporting the development of research and writing. Writing is not explicitly taught in this stage of the design degree — writing tasks in this and other subjects focus primarily on reflective journal writing. Many students struggled with moving between genres (descriptive, narrative, analytical; creative, imaginative, speculative), the use of verb tenses, point of view (first, second or third), and employing referencing conventions. The short form meant that many students were overconfident, underestimating the task and leaving it to the last minute.

### 2.2.3. *The importance of synthesis*

Once students really began to write, they often described an ‘ah-ha’ moment: the realisation that summative writing, to be effective, needs to concisely synthesize and communicate complex concepts and broad-ranging research.

### 2.3. *Conclusions*

Although the writing briefs were relatively simple, students were being asked to navigate complex conceptual and psychological territory. Therefore, workshop support, timely explanations, examples and guidance were required. The shift in focus between the three pieces was effective in balancing descriptive, evidence-based analysis with imaginative, creative process. Students were able to critically speculate in response to their findings. Writing in response to this evidence-based research enabled students to establish clear design constraints from which to extrapolate. The word limitations, mixed genre (or voice), and the sequential writing were key. The task proved to be well structured, with scaffolding, workshopping and casting of the focal points of each sequential piece of writing essential.

## 3. SPECULATIVE WRITING: SCOPE AND POTENTIAL IN DESIGN AND TECHNOLOGY EDUCATION

Speculative writing is a transformative tool for initiating creative and critical design thinking in response to preferred futures or future-based design scenarios. It enables speculative thinking to be captured and communicated, but also expanded, propagated, and developed. Speculative thinking can be more effectively critiqued in a written form, and speculative writing practices can enable the development of preferred future narratives which can specify design constraints and contexts. Speculative writing has the capacity to ‘re-animat[e] thought’ (Ingold, 2006), enabling students to respond to the challenge of creating preferred futures through design. Speculative writing facilitates an authentic engagement with future design narratives by allowing challenging questions to emerge and authentic design problems to be identified. The result is meaningful, critical design solutions in response to specific contexts.

## 4. RESOURCES

Speculative design, design futuring, futuring glossary, definitions, STEEP analysis: <http://www.utsdesignindex.com/researchmethod/futuring-with-scenario-design/>

Speculative objects: <http://www.utsdesignindex.com/researchmethod/speculative-objects/>

Dezeen case studies in Design and Technology: <https://www.dezeen.com>

Near Future Laboratory: Design Fiction Product Design Work Kit 0-TBD-D012 <https://shop.nearfuturelaboratory.com/products/design-fiction-product-design-work-kit>

Situation Lab: The Thing from the Future <http://situationlab.org/project/the-thing-from-the-future/>

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# Developing Creativity and Imagination in Native Hawaiian Adolescents

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Students in grades 6 through 9 at a small language immersion PK-9 school lacked the creativity and imagination to successfully solve design challenges. The purpose of this study is to identify how traditional Native Hawaiian cultural practices might be used to successfully support the development of creativity and imagination in Native Hawaiian children ages 13 through 15. Using qualitative methods, twenty Part-Native Hawaiian students, ranging in age from 13 through 15, engage in adaptations of cultural practices in order to identify strategies, methodologies, and practices capable of supporting the development of characteristics of creativity and imagination. Native Hawaiians are underrepresented in STEM fields and are underserved by a public education system committed to traditional Western pedagogies and practices. It is hoped that identifying pathways through native indigenous language and cultural practices will support the development of creative thinking and imaginative thought.

*Key Words: Native Hawaiian, Cultural practices, Creativity, Imagination, Curricular reform.*

## 1. INTRODUCTION

Hawai‘i is an isolated island state with a very unique situation with regards to our renewable and non-renewable resources. It finds itself dependent on others for many of its resources that cannot be grown and/or manufactured within the constraints of its boundaries. Consequently, it sees a “steady deterioration of public infrastructure ... the vulnerability of Hawai‘i in a volatile global energy market, possible interruptions in ... critical food supplies, [and] threats to our fragile island ecosystems” (Hawai‘i 2050 Sustainability Task Force, 2008, p. 5) making sustainability a top-tier issue and concern, especially when viewed from the lens of Hawai‘i’s “long-term limits of growth” (Hawai‘i 2050 Sustainability Task Force, 2008, p. 5). This is just one example of the problems the State of Hawai‘i faces in the near future, and it is a problem currently without a solution. In the words of Richard Riley, Secretary of Education under Clinton, “We are currently preparing students for jobs that don’t yet exist...using technologies that haven’t yet been invented...in order to solve problems we don’t even know are problems yet. The United States is quickly losing its intellectual commodities, as schools continue to hold fast to the pedagogies and practices of years past (Kerr & McKay, 2013).

Today’s students are the workforce departments of education are preparing to solve problems like the one described above. “One of education’s chief roles is to prepare future workers and citizens to deal with the challenges of their times” (Trilling & Fadel, 2012, p. 4). Unfortunately, the current educational system fails to support the achievement of culturally diverse students, and it has been failing since 1928, as indicated in the release of the Meriam report (2009) and the testimony given at the Senate Committee on Labor and Public Welfare (1969).

Technology continues to grow, but more important to education and curricular reform, is the increased complexity of its growth. This exponentially growing change can be attributed to what Schwab (2015) is calling the Fourth Industrial Revolution, where it is “building on the Third [Industrial Revolution and] ... is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres” (para. 3). Preparation of students to engage and participate in this revolution requires the development of creativity and innovative thinking.

### 1.1. Research question

This research study investigates Native Hawaiian adolescents' ability to develop the critical skills of creativity and imagination and is guided by the following research question:

How might traditional Native Hawaiian cultural practices and the design process support the development of creativity and imagination in Native Hawaiian students in grades 6 through 9?

## 2. LITERATURE REVIEW

### 2.1. Creativity and innovation

Creativity “is a useful and effective response to ... change... [in which] originality...and flexibility [are] important parts of it...it is reactive...[and] one of the engines of evolution” (Runco, 2004, p. 658). Creativity is most often described based on specific traits or characteristics of a creative person because creativity derives from a creative personality (Guilford, Creativity, 1950). It is the development of original ideas that can be useful or influential.

The Fourth Industrial Revolution, presented above, differentiates itself from the first three in its “velocity, scope, and systems impact ... [allowing it] an exponential rather than linear growth” (Schwab, 2015) rate. In addition to the concept of a fourth industrial revolution, the complexities of technology and technological advancements – artificial intelligence, robotics, nanotechnology, and biotechnology, to name a few – indicate a greater need for creative thinkers and innovators. Table 1 illustrates how the top ten job skills will evolve over a five-year period as identified by Gray (2016). The upward movement of critical thinking and creativity in the top ten demonstrates the importance of education moving away from traditional, siloed, twentieth century pedagogy to inquiry-, problem-, or design-based pedagogy (World Economic Forum, 2016) because “creativity is a useful and effective response to evolutionary change” (Runco, 2004).

Table 1. Top 10 job skills.

In 2020	In 2015
1. Complex Problem Solving	1. Complex Problem Solving
2. Critical Thinking	2. Coordinating with Others
3. Creativity	3. People Management
4. People Management	4. Critical Thinking
5. Coordinating with Others	5. Negotiation
6. Emotional Intelligence	6. Quality Control
7. Judgment and Decision Making	7. Service Orientation
8. Service Orientation	8. Judgment and Decision Making
9. Negotiation	9. Active Listening
10. Cognitive Flexibility	10. Creativity

### 2.2. Inquiry-, problem-, and design-based pedagogy

Commonalities of inquiry-, problem-, and design-based pedagogy include student construction of knowledge, a problem or design challenge, and the implementation and application of a procedural methodology (Crippen & Archambault, 2012; Donna, 2012; Sanders, 2009; Wells, 2013). Well-developed and detailed problems or design challenges allow for student responsibility and accountability for his/her learning, while the teacher facilitates student learning through purposeful and thoughtful questioning (U.S. Department of Education, 1996). Added to this pedagogical practice is the implementation and application of a procedural methodology. With an inquiry-based problem, students employ the scientific method, and with a problem- or design-based challenge, students employ the technological or engineering design process.

#### 2.2.1. Engineering design process

The engineering design process is procedural steps engineers and engineering teams utilize to solve problems. The process is iterative, meaning that steps are repeated as often as necessary to provide the best possible solution to a given problem. The iteration is a key aspect of the engineering design process because it allows

for continued improvements (Ertas & Jones, 1993; Siew, 2017). The engineering design process was employed to provide a step-by-step guide for students to develop an understanding of design.

### *2.2.2. Instructional practices promoting creativity traits*

Inquiry-, problem-, and design-based pedagogies “focus on particular elements, such as thinking skills, ... as well as cognitive components that influence creativity” (Morin, Robert, & Gabora, 2018, p. 151). Divergent thinking, a cognitive component, supports the development of creative traits such as, flexibility, fluency, elaboration, tolerance of ambiguity, and originality, to name a few (Characteristics of creativity, pp. 2-3). The use of the above indicated pedagogies promotes and reinforces the development of “multiple thinking skills, to come up with different solutions and suggesting possible solutions indicating creativity” (Birgili, 2015, p. 78).

### **2.3. Culturally Responsive Teaching**

Culturally responsive teaching turns working with culturally diverse students into cultural brokers, providing students with curricula steeped in their culture and cultural practices. It allows teachers to capitalize on student strengths by using students’ “cultural knowledge, prior experiences, frames of reference, and performance style” (Gay, 2010). “The curriculum used by culturally response teachers provides rigorous, standards-based content that requires students to think critically to solve problems that are placed within a relevant context” (Kaui, 2016, p. 31). The incorporation of language and cultural practices in curricula aligns with culturally responsive teaching strategies.

“Cultural practices are shared perceptions of how people routinely behave in a culture” (Frese, 2015, p. 1327) and can cover a plethora of topics. An online search generates such topics as, “The state as cultural practice,” “Science as cultural practice,” and even “Curriculum as cultural practice” (Search, 2018). It would seem that nearly everything from an individual to an organization and from a content area to an athletic sport can be classified as a cultural practice. Cultural practices helped to make the foreign concept of a design challenge relevant to students. As students who are Part-Native Hawaiian, the integration of Native Hawaiian cultural practices provided students with a bridge to their learning.

## **3. METHODOLOGY**

### **3.1. Participants**

Twenty students, six girls and 14 boys, participated in this research study, which spanned two school years (August 2016 through April 2018). During the first year of the study, there were 19 participants (five girls and 14 boys) in seventh and eighth grade. After this first year, three girls and two boys left the study because they enrolled at a different school. However, the data for these students are still included for year one. During the second year of the study, there were 14 returning students (two girls and 12 boys) and a new attendee (one girl) for a total of 15 participants in year two. All 20 participants are Part-Native Hawaiian, 16 participants qualify for free- and reduced-lunch, and all began the study as either 13 or 14 years of age and completed the study as either 14 or 15 years of age.

### **3.2. Materials and procedure**

This study was designed to investigate how traditional Native Hawaiian cultural practices and the design process might support the development creativity and imagination in Native Hawaiian students between the ages of 13 and 15. Prior to this study, participants were exposed to a variety of Native Hawaiian cultural practices, including, but not limited to, fishing methods, hand crafting with plant fibers and/or leaves, and dancing. However, participants were not exposed to the engineering design process and/or performance and task design challenges.

Before the start of the 2016-17 school year, the principal investigator developed a design curriculum including the engineering design process and a variety of performance and task design challenges. This curriculum was implemented within science and math courses taught by the Principal Investigator. The curriculum began with an eight-lesson unit introducing the engineering design process. Table 2 outlines the specific process used.

Table 2. The engineering design process.

Step	Definition
Identify	To demonstrate understanding of the problem, the student will define the problem in his/her own words.
Investigate	To understand what others already did to solve similar problems, the student will gather existing information and data.
Imagine	To generate possible solutions, the student will use his/her investigation and creativity and imagination to brainstorm multiple solutions.
Plan	To focus on a single solution, the student will create drawings and prototypes to figure out details.
Create	To determine the validity of a focused solution, the student will build the planned solution.
Test	To collect data on the success of a focused solution, the student will test his/her built solution.
Improve	To improve on the focused solution, the student will revise and/or modify the test solution using collected data.
Communicate	To share ideas, the student will present a detailed analysis of the second iteration.

The curriculum was intentionally developed to be dynamic and change based on teacher observations and student reflection and feedback. The first year was primarily used to develop knowledge and skills of the design process and to develop experience with design challenges. The second-year curriculum was developed using year one data between years one and two. In the second year, the curricular focus was on the use of cultural practices within the design challenges. The second-year design challenges were modified by the principal investigator to better integrate the specific cultural practice used.

The engineering design process unit allowed participants to learn and work through the process with a single design problem. At the end of the first unit, approximately eight weeks, the participants completed one design challenge per two weeks, with the challenges alternating between a performance challenge and a task challenge. Performance challenges, as the name implies, requires participants to solve a problem which involves some type of performance, be it acting, singing, or sound making, while task challenges, again, as the name implies, allow participants to solve problems by carrying out specific tasks. Regardless of the type of task, some challenges required the use of everyday materials, e.g., paperclips, straws, pipe cleaners, craft sticks, string/yarn, cups, etc., and other challenges forced you to work without any materials.

For each design challenge, participants worked in teams with no more than three other classmates. Teams were used to dispel any fear participants might have about trying new ideas and/or concepts, as well as to teach valuable skills around collaboration and cooperation (DuFour & Eaker, 1998). If any investigator observed two participants working together more than once, the pair was split up and regrouped.

### 3.3. Qualitative data

Qualitative data was collected using student reflections. Prompts used are found in Tables 3. In year one, participants were asked to respond to prompts one through six; and in year two, prompts one through nine.

Table 3. Self-reflection prompts.

Description
1. Did your team successfully complete the challenge?
2. What do you believe made your team's design successful? Why? If you do not believe your team successfully completed the challenge, what do you believe made your team's design unsuccessful?
3. Did your team implement the different steps of the engineering design process? Please provide a detailed explanation of the different steps implemented and support your explanation with supporting evidence from your design challenge.
4. Describe the different ways your team used the given materials for this design challenge.
5. Since this design challenge only allowed you to complete six of the eight steps, how might you improve on your team's design? Please provide detailed examples and descriptions to support your response.
6. What might you have done to better support a successful team design? Please provide detailed examples and descriptions to support your response.
7. Have you ever used and/or participated in the given Native Hawaiian cultural practice?
8. If you answered, "Yes," to number seven, how did your prior knowledge influence your design challenge solutions? Please provide detailed examples and descriptions to support your response.
9. If you answered, "No," to number seven, what was something new you learned about the Native Hawaiian cultural practice? What are some ways you might utilize this cultural practice in future design challenges? Please provide at least two different examples with a detailed description.

### 3.4. Quantitative Data

Quantitative data was collected using creativity characteristics defined by Guilford, J.P. (1973, p. 8), as shown in Table 3. This data was used to correlate principal investigator's observations with participants' reflection and feedback. Participants were rated on a scale from zero to five, with zero indicating student does not demonstrate the described characteristics and five indicating the student demonstrates the described characteristic 100 percent of the time. Lack of correlation between the two measures suggested an in-depth discussion with the specific participant.

Table 3. Characteristics of creativity descriptions

Description
T1. Asks many questions, often challenging the teacher and the textbook.
T2. Experiments with whatever is at hand.
T3. Work tends to be off the beaten track, with much humour and playfulness.
T4. Often bored with recitation and memorization of facts, preferring to talk about ideas and facts, preferring to talk about ideas and problems.
T5. Has a reputation among the other students and teachers for wild and silly ideas.
T6. Has much energy, which gets the student in trouble at times.
T7. Feels strongly about many things and often expresses feelings.
T8. On examinations, sometimes comes up with unexpected, even "smart-alecky" answers.
T9. Likes to work alone.
T10. Resented by others because of crazy ideas and forcefulness in presenting and pushing those ideas.
T11. Does not usually appear to be working hard, but does fairly well at examination time.
T12. On special projects, shows unusual capacity for originality, concentration, and just plain hard work.

## 4. RESULTS

This study investigated how Native Hawaiian cultural practices and the design process might support the development of creativity and imagination in Native Hawaiian adolescents. Data for this research study was collected via student reflection responses completed at the end of a design challenge. Data were analyzed, and themes identified.



## **4.1. Year One**

In year one, participants completed a performance or task design challenge once every two weeks. At the end of each challenge, they completed a self-reflection providing feedback of their learning and achievement relating to creativity and imagination. A successfully completed design challenge was categorized as any design challenge that met all the design constraints using the given materials. In year one, there were 40 design challenges. Of the 40 design challenges, four were successfully completed by four different teams in the fourth quarter. Researchers reviewed and analysed participant self-reflection responses, and three themes emerged.

### *4.1.1. Missteps*

Participants consistently indicated not properly working through the engineering design process. “Everyone on my team, including me, went straight to building something with our materials” (Participant5621000140, 2016). Regardless of the time spent learning, practicing, and implementing each step of the engineering process, participants did not work through each step. “I dunno why I don’t follow the EDP steps. I just wanna get started on building stuff” (Participant5621000083, 2016). August and September 2016 participant responses showed all participants immediately starting at the “Create” step of the engineering design. However, January through June 2017 data showed four responses indicating the team worked through each step of the process. Participant5620900424 was a member of each team, suggesting this participant as the catalyst for working through the process. Teacher observations agreed with student responses.

### *4.1.2. Unsuccessful completion of design challenge.*

Data analysis revealed an unsuccessful design challenges was attributed to not properly working through the design process, while a successful design challenge was attributed to teams who correctly worked through each step of the design process.

This is the 3rd design challenge my team finished successfully. I think this is because we are doing the whole steps. When the team I’m has worked through the whole steps, we won. But when I was on teams and we didn’t do the steps, we lost (Participant5620900424, 2017).

This participant was the only one who suggested his/her team’s success might be connected to properly working through the engineering design process.

### *4.1.3. Perseverance*

The third theme identified related to individual and team perseverance. Participants indicated that they could better support their teams’ success by persevering. While 60 percent of the participants indicated perseverance as something that could be improved, their reasons for a lack of perseverance were not the same. “No one on my team was listening to me, so I put my head on the table. We ended up not even making a solution. I had a good idea, but didn’t tell anyone about it” (Participant5620900408, 2016). “I was getting mad that my tower kept falling over and the paperclip wasn’t holding it up like I thought it would. No matter how much I tried nothing worked so I quit” (Participant3571000131, 2016). In addition to not being heard and frustration, participants also attributed their inability to persevere to team bickering and lack of solution ideas.

## **4.2. Year Two**

The most noticeable improvement in year two was the increase in the number of successful design challenge completions by teams. Participant response analysis for the second year of the study showed an increase from a 20 percent success rate to a 45 percent success rate, demonstrating a 125 percent increase in success rate. In year two, students also completed 40 design challenges, 18 of which were successfully completed. Additionally, data analysis also identified two themes from participant responses.

### *4.2.1. Material investigations*

The first identified theme dealt with material investigations. This year, in response to other comments from student self-reflection responses and verbal conversations, the principal investigator added material investigations to the curriculum. Material investigations are short ten-minute lessons in which participants are given a single material, like a paper clip, straw, or craft stick. These investigations were done in the first quarter. In ten minutes, they must identify as many ways the given material can be used. These material investigations started off slowly; however, as participants began competing, participant interest peaked. “The material investigations are way fun! I can definitely see how alot of the stuff we use can be used in other ways”

(Participant5620900036, 2018). Principal investigator observations confirmed participant appreciation of material investigations and the increase in flexible use of materials. This increase in the flexible use of materials was primarily witnessed during the brainstorming phase of the engineering design process.

#### 4.2.2. *Brainstorming*

Throughout the second year, 35 percent of participants began purposefully using the process. This meant they began methodically working through the process to identify possible solutions for each design challenge. “Last year, I wanted to build right away, so I did, but this year, cuz we started learning how to use materials, I started brainstorming. I saw that I could only use what I know about materials if I brainstormed first” (Participant3571000131, 2016). Other students substantiate this participant’s comments and emphasize the importance of the brainstorming step when solving design challenges.

## 5. DISCUSSION

The mantra of education innovators, like Sir Ken Robinson (Talk, 2006), Tony Wagner (Wagner, 2012), and Kyung Hee Kim (Kim, 2009), is that America’s current educational system is killing creativity. Departments of Education around the United States allow traditional educational systems to educate creativity and imagination out of American children.

### 5.1. *Curricular Reforms*

Principal investigator observations and participant responses to the design challenge self-reflections help identify curricular aspects that prove to be successful in developing specific characteristics of creativity. For example, the material investigations helped develop participant flexibility in using objects and in small and large group discussions. The design challenges themselves increase participant curiosity at how to solve a problem. While participants did not once reference their cultural practices integrated within the design challenge, observations illustrate student ability to make connections between practices. For example, the resources of one cultural practice, in this case, wili style lei, intertwines itself with the needs of another cultural practice, weaving. The practice of one leads to the perpetuation of all.

### 5.2. *Cultural Practices*

Year two’s design challenges implemented and applied a single cultural practice – lauhala, whose scientific name is *pandanus tectorius*. One hundred percent of the participants knew of the Native Hawaiian cultural practice of weaving lauhala, but only 75 percent, or 15 participants, had woven lauhala prior to these design challenges.

Regardless of this prior knowledge, the data does not suggest a singular focus on the cultural practice as the catalyst for developing creativity and imagination. Recorded observations indicated only two groups utilizing prior knowledge to somehow incorporate lauhala weaving into the group’s solution. Of those two groups, only one group, specifically one participant, was flexibly weaving lauhala in a new and original way. However, based on student self-reflection responses, there were simply too many variables being manipulated in this research study, which made it difficult to try to identify a single support for student development of creativity and imagination.

As an underrepresented and underserved group, it is imperative for Native Hawaiians to better innovate throughout the day. Fiddle with random objects more, draw a line picture and then color it, and/or dance the night away with friends. These seemingly innocuous activities support the development of the characteristics of creativity, and when we are preparing students for non-existent jobs, then it is our responsibility to educate the whole mind.

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# Connecting Authentic Innovation Activities to the Design Process

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Although history is full of inventors and innovations, principles underpinning the design (or innovation) process were only first described in the 1960's and 1970's. Beckman and Barry (2007) connect the design process to learning by experience, a process linked to experiential learning, and a forerunner of authentic learning. This study concerns an authentic innovation project, in which 13 groups of upper secondary school students (aged 16–17 years) solved real-world problems of their choice. The five-week innovation project offered students possibilities to think, design, discuss and reflect. The specific aim of this study is to present and analyse the activities that took place at different stages of the innovation/design process by posing the following research question: Do the students taking part in the innovation project engage one or more phases of the design process? Our results suggest that students with little or no previous experience of innovating or designing, not only solve the tasks they set out to solve, but also do so in a manner that mimics the way a trained inventor might work. These observations are closely associated with the learning models described by Beckman and Barry, and have implications for the teaching of design and innovation processes.

*Key Words: Authentic learning, Innovation project, Upper secondary school, Design process.*

## 1. INTRODUCTION

“An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations” (The Organisation for Economic Co-operation and Development [OECD], 2005, p. 46). To be able to perform such an implementation and thus produce an innovation, creativity is necessary, and “design is what links creativity and innovation” (Cox, 2005, p. 2). Problem solving and design are ubiquitous in technology education research. However, there have been few attempts to link the design process with concrete authentic innovation programmes (Mioduser, 2009; Schooner, Nordlöf, Klasander, & Hallström, 2017; Williams, 2000). As part of a 2016 innovation project at a Swedish upper secondary school, students worked in groups to solve real-world problems of their own choice. The specific aim of the current study is to present and analyse the activities that took place at different stages of the subsequent innovation/design process by posing the following research question: Do students participating in the innovation project engage one or more phases of the design process?

## 2. THE INNOVATION / DESIGN PROCESS

Humans invent things to improve their daily life. We know of stone tools dating from 2.6 million years ago, but there could be even older artefacts dating back 3.3 million years (Domínguez-Rodrigo & Alcalá, 2016). Anthropologists are also of the view that humans co-evolved with the tools that they produced (e.g. Stiegler, 1998). But, exactly how the shape or function of tools were decided upon, in terms of being operationalized as a design process *per se*, was only first described in the 1960's and 1970's through the pioneering work of

scholars such as Herbert Simon, John Christopher Jones, Bruce Archer, Gerhard Pahl and Wolfgang Beitz (Bayazit, 2004; Pahl, Frankenberger & Badke-Schaub, 1999).

According to Simon (1996), innovation activities are really about design, and that “Everyone designs who devises courses of action aimed at changing existing situations into preferred ones” (1996, p. 111). There is no one model to represent the design process. Depending on area of application and tasks, designers tend to use different models. In general, they start with an ill-defined problem and diverge to reveal different aspects of the problem. This is followed by converging toward a single, defined problem. The defined problem is then treated in a similar way to find the solution – divergence to find different possible solutions and convergence to decide on the most favourable (see Fig. 1). This method was introduced in 2005 by the Design Council in the form of the *Double-Diamond* model of design (Design Council, n.d.). Each of these phases encompasses a cyclical process where observations lead to ideas, which in turn, lead to prototypes, followed by testing and subsequent observations, and so forth. An iterative spiral is pursued until a desired outcome is reached (Fig. 2) (Norman, 2013).

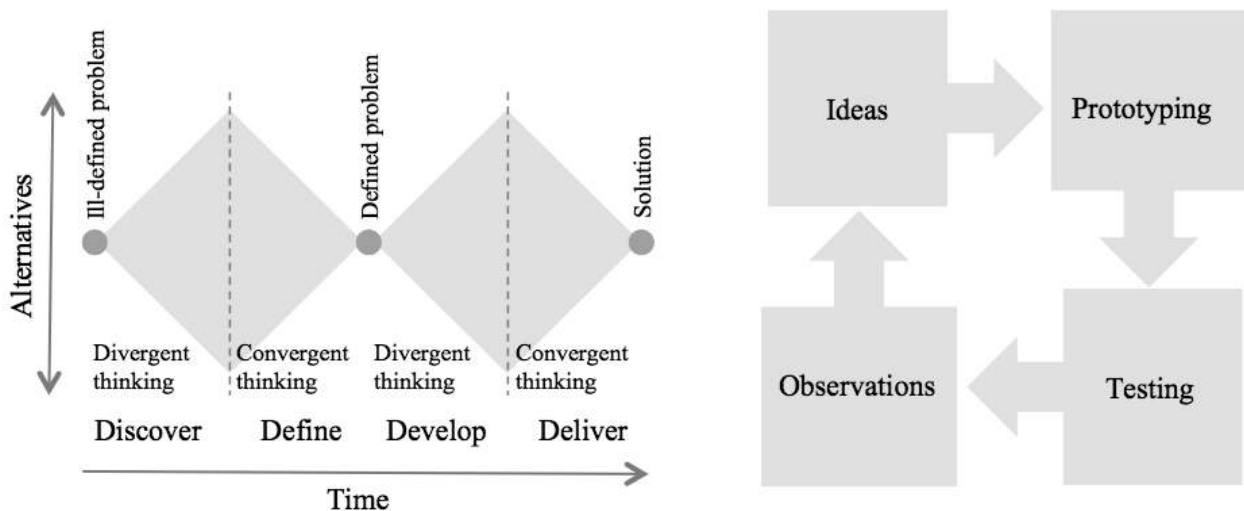


Figure 1 (left). The double-diamond model of design (Modified from the Design Council, 2005, and Norman, 2013).

Figure 2 (right). The iterative spiral (Modified from Norman, 2013).

Even if there are a number of different ways to describe the design process, they all share one common feature in that they comprise of distinct elements and phases (Beckman & Barry, 2007; Norman, 2013; Owen, 1993a; Pahl & Baitz, 1996).

In describing the connection between design and innovation, Owen (1993b) stated that, “design is the creation process through which we employ tools and language to invent artefacts and institutions” (p.2). In line with Cox’s earlier assertion that design is what connects creativity and innovation, Owen suggests that there is an innovation process that fits all areas of application even though tools and techniques, as well as theory versus practice, may differ (Cox, 2005; Owen, 1993b).

### 3. AN INNOVATION PROJECT IN TECHNOLOGY TEACHING

It is obligatory for all students in the upper secondary Technology program in Sweden to participate in the Teknik 1 (Technology 1) course. Teknik 1 contains elements such as problem solving, design, materials and material processing, basic drawing, modelling and CAD techniques. The innovation project in focus in this study was implemented at a Swedish upper secondary school (Svärd, Schönborn, & Hallström, 2017) and consists of a five-week period in which students solve real-life problems in groups. The problems should be pertinent to students’ lives and be associated with non-trivial solutions. From a student point of view, one major challenge to overcome is realising that there are no specific instructions provided for the task and teachers only offer scaffolding support. Therefore, the students have to plan and carry out their own projects, including searching for necessary information in areas such as materials, manufacturing and markets, as well as making various financial estimations. They are also requested to develop models, or in some cases, fully operational

prototypes of their inventions. For digital solutions, pictures of the modelled interface are expected. This period ends with an exhibition where the students present their results and explain the functions to fellow peers, interested observers, as well as invited professional inventors. The groups receive substantial feedback from the inventors about all aspects of the process.

When students have to take responsibility for their own learning, as in the described innovation project, they typically enter unknown territory. Schooling today often emphasises tasks that are intended to be solved in one particular way (Blumenfeld, Soloway, Marx, Krojcek, Gazdial, & Palinvar, 1991; Blumenfeld, Marx, Soloway, & Krajeik, 1996; Newmann, Bryk, & Nagoka, 2001). Observations in the classroom support this when students continuously ask if they are performing the task in the correct manner, and how the teacher intends grading their work. In the innovation project, it eventually becomes apparent to the students that there are no “right” or “wrong” solutions since the students themselves create and perform the task. The teacher offers nothing more than scaffolding help such as being present, listening to students’ thoughts, and offering advice when asked. This could potentially offer the students an optimal learning environment, since “people grow best where they continuously experience an ingenious blend of challenge and support” (Kegan, 1994, p. 42).

The iterative spiral of the innovation process (Fig. 2) shares a relationship with Kolb’s Experiential Learning Theory (ELT) since it contains both problem solving and interplay with the environment (Svärd, Schönborn & Hallström, 2017). In this respect, Kolb and Kolb (2013) has stated:

For a learner to engage fully in the learning cycle, a space must be provided to engage in the four modes of the cycle—feeling, reflection, thinking, and action. It needs to be a hospitable, welcoming space that is characterized by respect for all. It needs to be safe and supportive, but also challenging. It must allow learners to be in charge of their own learning and allow time for the repetitive practice that develops expertise. (p. 20)

Ideally, each group of students should be composed in such a way that they are different in their approaches of perceiving and transforming information. For example, some students prefer abstract conceptualizations and reflection, while others prefer learning by doing (Kayes, Kayes & Kolb, 2005). The groups should not remain in either the concrete or abstract realms, but move freely between them during the iterative innovation process. One way of describing this flux has been suggested by Kolb and Kolb, and others (see Fig. 3). The students do not need to follow the steps in the order as described in Fig. 3, nor do they have to spend equal time within each represented quadrant (Kolb & Kolb, 2013).

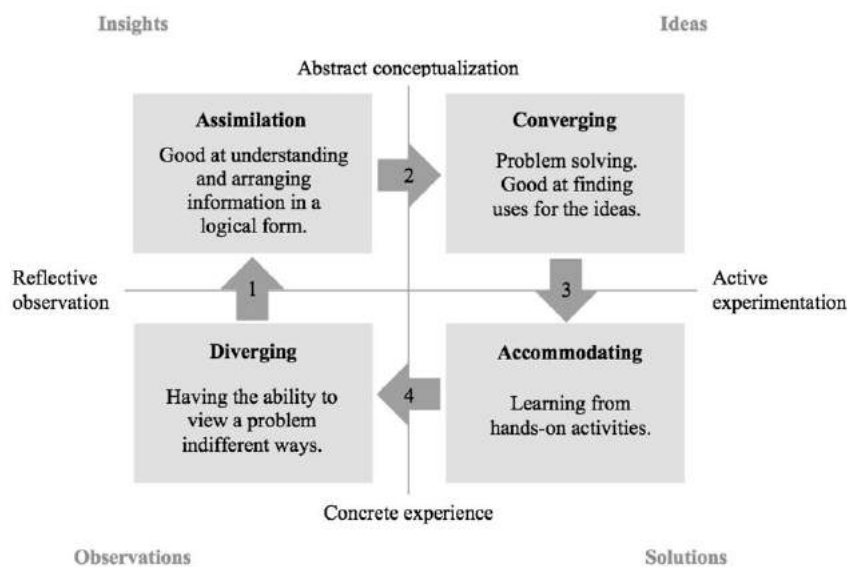


Figure 3. The innovation process as a learning model based on Kolb’s learning style inventory. Processes designated by arrows consist of: 1. Problem finding, 2. Problem selecting, 3. Solution finding, and 4. Solution selecting. (Modified from Kolb & Kolb, 2013; Owen, 1993a; Beckman & Barry, 2007).

There are advantages and disadvantages of using this method. Scholars such as Gardner, in his “Multiple intelligences” theory, and Kolb’s “Learning style inventory” have presented theoretical frameworks based on the premise that different people learn in different ways. The innovation process as a learning model supports these approaches, since it offers multiple ways to investigate a problem. In contrast, it must also be acknowledged that there are students that are uneasy about unfamiliar learning environments and the possible risks of failing. In this regard, Kolb and Kolb (2013, p. 20) suggests that, “students will often say, ‘But I don’t have any experience’ meaning that they do not believe their experience is of any value to the teacher or for learning the matter at hand”. In these cases, one can remind students about Elon Musk’s utterance in an interview for *Fast Company*: “There’s a silly notion that failure’s not an option at NASA. Failure is an option here [at SpaceX, authors comment]. If things are not failing, you are not innovating enough” (Reingold, 2005).

#### 4. METHOD

This study investigates the activities during the main, five-week phase of the innovation project. Data was collected in the form of responses to a series of written questionnaires administered at the end of each of nine lessons included in the innovation project. The questionnaire was answered once per group, wherein a total of 13 groups, each consisting of three to four students, participated in the project. Three questions were answered by ticking multiple-choice boxes together with the option to provide additional comments about a respective day’s work. The same questionnaire was administered every lesson. The questions comprising the questionnaire were as follows (see the Appendix for the complete questionnaire):

- 1) How do you think you performed today?
- 2) If you answered *Poor* or *Not so good*, then why?
- 3) What kind of work did you perform during the lesson?

This paper focuses on student responses to question three above, which concerned the activities performed during each lesson.

Tiwari (2008) has suggested an innovation process consisting of three steps, namely *Conception*, *Implementation* and *Marketing* (Fig. 4). This model represents multiple aspects of the currently explored innovation project. Furthermore, if one subsumes both Abstract Conceptualization components (Insights and Ideas) from Fig. 3 into the Implementation step, then it also represents aspects of the innovation process as a learning model as described by Kolb and Kolb (2013). In this regard, analysis of responses to question three (Activities) involved connecting students’ answers to each of the steps described in Fig. 4.

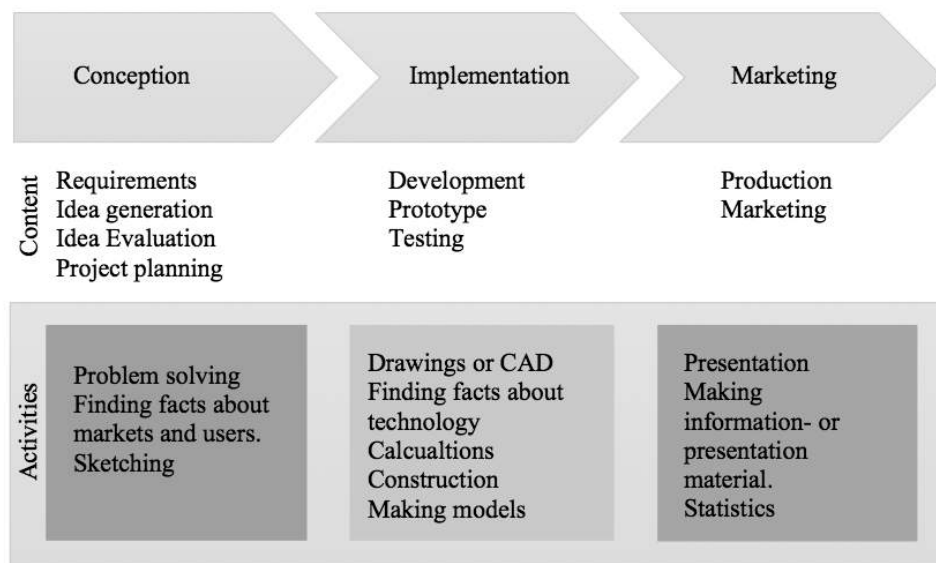


Figure 4. An innovation process suggested by Tiwari (2008) and corresponding activities during lessons as answered by each student group in the questionnaire. Respective colour coding of activities correspond to that used in Fig. 5 (see later).



After each lesson, the selected answers from question three (see Appendix), "What kind of work did you perform during the lesson?" were sorted into the respective groups of Conception, Implementation and Marketing, as indicated in Fig. 4. If a group selected "Other", the written specification in the comment was used to designate the categorisation. If "Other" was not followed by a specification, the answer was omitted from analysis. As each student group was able to tick multiple options, a percentage of the answers from the total obtained, after that specific lesson in question, was calculated.

## 5. RESULTS

The daily activities that emerged from students' answers during the innovation project are presented in Fig. 5, which illustrates what activities were performed each day. The activities are sorted as per the Conception, Implementation and Marketing categories (cf. Fig. 4).

The results indicate that the Conception category dominated activities during the early initial phase of the innovation project. For the majority of project time, the Implementation phase is the most prevalent, while the Marketing category emerges saliently toward the end of the project. However, Fig. 5 also suggests that the students shuttle back and forth between the activities. For example, although Marketing activities are pronounced at the close of the project, activities related to Conception and Implementation are still being engaged at the same time.

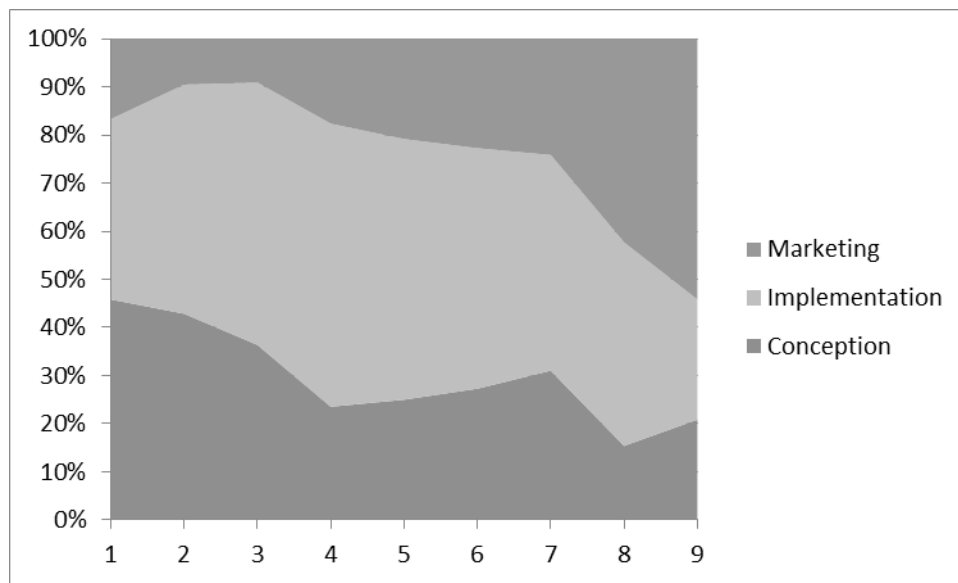


Figure 5. Graph representing the relative score (%) on Marketing, Implementation and Conception activities during the nine lessons of the innovation project in 2016.

## 6. DISCUSSION AND IMPLICATIONS

If the design process was linear, one might expect the results in Fig. 5 to be directed solely to Conception activities for the first and perhaps second lesson, as the groups chose a problem to solve. During the last lesson, the group's innovations were presented to other students and invited professional inventors at a school exhibition. In a linear process, this ought to result in the process closing with activities directed to Marketing alone. If the process was indeed linear, the lessons between the start and the end should be mainly Implementation activities. However, as demonstrated in Fig. 5, this is not the case. The presence and relative proportions of activities related to each of Conception, Implementation and Marketing at every single lesson indicate multidirectional and dynamic transitioning between the project phases (cf. Williams, 2000).

As Beckman and Barry (2007) point out, it is expected that a group working on an innovation moves fluidly between the different phases during an iterative process. It is also expected that results arise during the process that change the conditions in such a way that it produces new circumstances for the project, which presents the

need to return to an earlier point in the process. This would result in a pattern similar to that revealed in Fig. 5, where groups transition back and forth between scenarios as the project proceeds (Beckman & Barry, 2007).

The result that only 54% of the innovation activities during the exhibition were attributed to Marketing might be unexpected, since the exhibition is really all about presenting the results of the students' efforts. This result could be explained by the feedback the groups receive during the exhibition from fellow students as well as the invited innovators. This feedback induces new solutions as well as other ideas, resulting in exposing innovation activities that were prominent in earlier stages of the innovation process. One should also bear in mind that it is 54% of all activities, not the time spent on each phase. Thus one main finding of this study is that engaging all three innovation components or phases throughout, is conducive to an authentic design process. This also supports the notion that design and innovation are far from static endeavours (cf. de Vries, 2017). Rather, innovation is a dynamic process that relies on constant interplay between the three components, even if there are patterns of their relative salience over time.

Dewey stated that "...nothing takes root in mind when there is no balance between doing and receiving" (1934, p. 45). As suggested by the results of this study, the iterative and cyclical processes during the innovation project transit the groups' activities back and forth between practical and theoretical components; a movement that concerns all four learning modes – experiencing, reflecting, thinking and acting. In turn, Kolb and Kolb's (2013, p. 8) statement that "learning arises from the resolution of creative tension among these four learning modes" underpin the results that have emerged from the research thus far.

The group activities also mimic the type of teamwork that is widely used to develop new products or services nowadays. Furthermore, a group of students consists of different types of learners, a situation that takes advantage of students' diverse ways of learning and approaching a problem (Kayes, Kayes & Kolb, 2005). The outcome of this study raises new questions such as: Does an authentic innovation project improve learning and understanding of design and technology? Will the students show a subsequent increased interest in technology and problem solving? Are potential inventors of the future among these students? Aspects of these questions will be probed during the forthcoming phases of this research programme.

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## APPENDIX

Questionnaire items and possible answers administered after each lesson in the innovation project:

1. How do you think you performed today?

- Poor
- Not so good
- Good
- Very good

2. If you answered *Poor* or *Not so good*, then why?

- Disagreement in the group
- Uninspired
- Did not know what to do
- No help from the teacher
- Someone in the group was missing
- Other reasons (please specify)

3. What kind of work did you perform during the lesson? (multiple answers possible)

- Problem solving
- Drawings or CAD
- Finding facts about technology (materials, methods, etc.)
- Finding facts about markets or users
- Calculations (generally)
- Construction work
- Presentation- or information material (making or presenting)
- Statistics
- Sketching
- Making models
- Other (please specify)

# Cultural and historical roots for design and technology education: why technology makes us human

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In the continuing context of curriculum change within English education, this paper explores the cultural and historical roots of design and technology, as an educational construct, distinct from design or engineering, which exist as career paths outside of the school curriculum. It is a position piece, drawing on literature from a wide range of sources from writing and outside of the discipline. The authors revisit the original intention of design and technology as a national curriculum subject and within the contemporary challenges, highlight the historical and social importance of technology, including designing and making, as an essentially human and humanising activity. The aim being to contribute to the theorisation and philosophy of the subject, where typically practitioners tend to focus on practical and potentially mundane concerns. This paper asserts that technological human activity is rooted in technological innovation and determinism. The aim is to add to the literature and debate around the place and value of design and technology. The argument for retention of the subject, as part of a broad and balanced curriculum, is presented from a socio-technological perspective; recognising the value of the subject as cultural rather than a merely technical or as an economic imperative.

*Key Words: culture, design and technology education, philosophy of technology, socio-technological human activity.*

## 1. INTRODUCTION

This paper as a thinking piece, presenting the rationale for design and technology education as a discipline within the curriculum, at the local (school), national (statutory) and international (research and scholarship) level. Defences of the subject have been presented based on capability (Black and Harrison, 1985), design (Williams and Wellbourne-Wood, 2006), and within the context of the Science Technology Engineering Mathematics (STEM) agenda (Bell, 2016; Harrison, 2011). In this paper, we present a cultural and historical perspective on technology, positioning it as a fundamentally human activity (McLain, 2012; Bakhurst, 2007; Florman, 1987, in Mitcham, 1994) academically and culturally comparable with science, art, religion and sport (McGinn, 1978, in Mitcham, 1994).

This paper explores design and technology, as subject in the school curriculum (NCC, 1990: 23; DfE, 1995, 10; DfE, 2011b), focusing on cultural and historical factors relating to technological activity as a fundamental human trait, inextricably linked to the evolution of our species and societies. With this paper, we will not attempt to provide the historical context of the subject. Excellent historical accounts of the origins of design and technology education already exist, for example Atkinson (1990) who explores its evolution and transformation from handicraft through to design and technology as we know it today and Allsop and Woolnough (1990), who also investigated the contentious relationship between science and technology in the wake of the subject's emergence in the English curriculum. Precursors to design and technology have also been well documented, for

example Penfold (1987), who narrates the struggles of educators in the gradual emergence of a more designerly curriculum in pre-national curriculum England, the resistance to change, a theme described as subcultural retreat by Paechter (1995).

After design and technology's rise to prominence as the first subject to be defined by the National Curriculum in England (NCC, 1990; DES and WO, 1988) towards the end of the last millennium, two decades on the subject came under scrutiny of government advisors (DfE, 2011a) and outside commentators (Miller, 2011; McGimpsey, 2011). More recently, through the introduction of the English Baccalaureate (EBacc) and proposals to extend the "school day to include a wider range of activities, such as sport, arts and debating" (DFE, 2016: 21), the status of traditional academic subject has been elevated, leaving "little room, if any, for creative, artistic and technical subjects" (BACC for the Future, 2018) resulting in current challenges outlined by the Design and Technology Association (D&TA) for "teacher recruitment, reducing curriculum time, decreasing GCSE entries, access to professional development" (D&TA, 2018).

## **2. PROBLEM FINDING AND PROBLEM SOLVING**

In the contemporary educational context, design and technology faces several currently insurmountable problems. Adopting a suitably designed approach, let us engage with problem finding (McLain, 2012; Chand and Runco, 1993; Csikszentmihalyi, 1988). Design and technology has been identified as having "weaker epistemological roots" (DfE, 2011a: 24) than other curriculum subjects, such as mathematics, where the bodies of knowledge are clearly defined. In his work, Bernstein (1990) explores the nature of subjects, and their disciplinary boundaries, supporting the aforementioned concern regarding design and technology's epistemological basis. Bernstein's framework classifies subjects as having strong or weak boundaries, depending on how clearly bodies of knowledge can be defined. Utilizing mathematics as an example, whilst aspects of mathematical knowledge are included within other subjects, the knowledge is largely readily identifiable as belonging to the subject. For example, in design and technology a pupil may use knowledge of geometry when designing a prototype, but the knowledge is clearly mathematical. Whereas, again in design and technology, the same pupil may employ her imagination and communicate them through a sketch. In this typically design and technology scenario, both imagination and sketching are not the sole domain of the subject.

Taking a step back from education, technology is a complex phenomenon and term and "does not mean exactly the same thing in all contexts" (Mitcham, 1994: 152). If it is true that technology eludes a single universal definition by philosophers, it should not come as a surprise that any school subject directly related to technology would be similarly challenged. Reviewing philosophical discourse, Mitcham sought "to identify the stance and distinctions proper to thinking about technology philosophically" (p.267), presenting "set of quasi-empirical categories for speaking about technology" (p.269): technology as object, as knowledge, as activity and as volition.

The following discussion will elaborate on the challenges in defining design and technology using Bernstein's classification and framing and Mitcham's modes of the manifestation of technology, scoping out the subjects epistemological problem. The agreement will be developed proposing an historical and cultural rationale for the inclusion of design and technology in a board and balance curriculum, as a focal point for socio-technologic human activity, drawing on thinking from social constructivism, cultural psychology and neuroscience to challenge the academic hegemony.

## **3. THEORETICAL FRAMEWORK**

This paper explores literature from a variety of disciplines to discuss technological activity, within a social constructivism framework in the educational traditions of Dewey and Vygotsky. Our analysis considers technology, including tools and artefacts, as "cultural entities" and is informed by an "object-orientedness of action" view of the mind (Engeström, 2009: 54). Latour (2008) and Harman (2002), building on Heidegger's philosophy of tool use, discuss the nature of objects and the influence they wield on human behaviour and development. Vygotsky discussed the importance of technological activity as a key to understanding the mind, and the link between tool use and speech (Tappan, 1997; Vygotsky, 1978).

Cole (2007) describes Wartofsky's assertion that the "creation of artefacts, including the words of one's language" is distinctively human. Wartofsky (1979) outlines three levels of artefact (Table 1) with both technological and social tools as primary artefacts used in the production of the means to perpetuate the species. Secondary artefacts incorporate primary artefacts and their application, including the transmission and preservation of technical knowledge. Tertiary artefacts enter an imaginary realm, allowing for praxis to be transferred and transformed "beyond the immediate context" (p.91).

Table 1. Wartofsky's taxonomy of artefacts

Level	Description
<i>Primary:</i>	Technological (e.g. a hammer) and social (e.g. words) tools.
<i>Secondary:</i>	Includes the preservation and transmission of skills or modes of action.
<i>Tertiary:</i>	Creativity, imagination and transfer beyond the immediate context.

According to Bell et al. (2017) as a single subject, in part because of its interdisciplinary nature, design and technology, struggles to surrender its axioms, which is a contributory factor in the subject's failure to establish itself as a single discipline (Bell, Morrison-Love, Wooff and McLain, 2017). In the following sections we explore the 'problem' on the basis of an assumed ontological richness, if a not yet defined epistemological as one; as an artefact mediated discipline that not only uses artefacts and tools, but one that designs, makes and evaluates them.

#### 4. BERNSTEIN'S CLASSIFICATION AND FRAMING OF EDUCATIONAL KNOWLEDGE

In this section we will explore design and technology through the lens of Bernstein's classification and framing of educational knowledge (1971).

In his work, British Sociologist Basil Bernstein explores social class, performance at school and how education reproduces inequality. Through analysis of language, Bernstein (1990) sought to understand why children in lower social class do less well in school. In his early work he sought to distinguish between school [elaborate] and everyday [restricted] language in order to help analyse how children access and subsequently make sense of what is going on at school, in order to understand how children access and apply knowledge. He contended that the language used to teach a subject either enables or prevents access and found that children from working class backgrounds are less likely to achieve academically because of their limited understanding of the language used in school. Consequently, they are less able to access information received and subsequently communicate their own thoughts and ideas.

In earlier work, Bernstein (1971) codified subjects to define the distinction between different types of curriculum and illustrate the power [classification] relationships between what is taught, and the control [framing] of how knowledge is learnt. The collection code is characterised by subjects that have distinct external boundaries, well insulated from other disciplines. Within these are subject's knowledge is deemed to be 'sacred' and as such are subjects that reside within this category are deemed to be 'strong'. In contrast within the integrated code there is little insulation between subject boundaries. This may reflect thematic based work or homogenous teaching approaches and hence these subjects are classified as 'weak'. Within the integrated code the teacher needs to be able to handle uncertainty, there is a balance of power between the teacher and the student.

Brought about by the need to consistently embrace and adapt to change in order to meet curriculum demands, and reflect a world with ever progressing technological advancement, design and technology is characterised by perpetually shifting curriculum content, and a fluctuating knowledge and skills base that manifests and perpetuates subject instability and in doing so, it presents itself as a subject with weak external boundaries.

As a result, design and technology is a subject misunderstood, perceived to be lower in status than its well-established counterparts. In practice, in direct contrast to its STEM counterparts of science and mathematics, which are classified as subjects with strong external boundaries (Bernstein 2000, 1971), those working to

deliver the subject have to constantly justify design and technology's place as a subject of worth within a hierarchy of well-established curriculum subject disciplines. When presented as a single subject, with nomadic characteristics, and weak external boundaries that are difficult to define, design and technology manifests as a soft, applied subject (Bernstein, 2000, 1971), and as such, within the hierarchy of its academic counterparts finds itself in an uncomfortable, and often isolated place.

Bernstein provides a way to understand the difficulty that design and technology faces in justifying its place in the curriculum on epistemological grounds. Where the prevailing bias in education and education policy is towards definable knowledge, the relative ontological strength (Morrison-Love, 2017; McLain, 2012) of the subject is overlooked. The following discussion will explore the cultural and historical expression of technology.

## 5. MITCHAM'S MODES OF THE MANIFESTATION OF TECHNOLOGY

Acknowledging the complexity of technology, Mitcham (1994) presents an analysis of the issues in the philosophy of technology, which encompasses a breadth of philosophical perspectives from both inside (engineering) and outside (humanities) technology. Figure 1 (p.160) illustrates the developing framework, exploring the broad and interrelated categories of technology as object, technology as knowledge, technology as activity, and technology as volition.

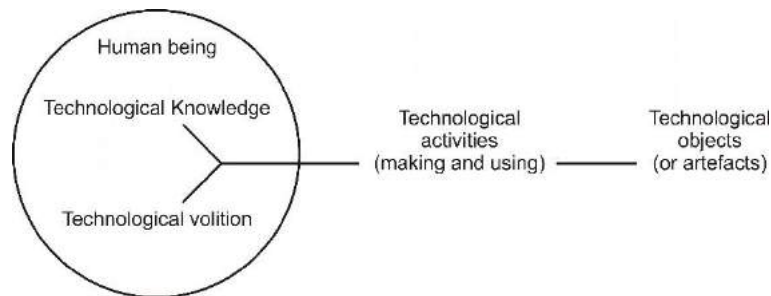


Figure 1. Mitcham's Modes of the manifestation of technology

The framework encompasses views as diverse as technological determinism, where technology is considered as influencing or controlling human activity (Roe Smith, 1994), to human freedom, where human will and creativity directs technology (Hickman, 2001; Feenberg, 1999). Further, it is open to viewing knowledge from both reductionist and transcendent perspectives.

Technology viewed as **object**, as defined by Mumford (1934, in Mitcham, 1994: 162) includes: clothing (“...utilitarian and decorative”), utensils (“... storage containers and instruments of the... home”), structures (“houses and other stationery artefacts”), apparatus (“...containers for some physical or chemical process...”), utilities (“... roads, reservoirs, electric power networks”), tools (“instruments operated manually... to move or transform the material world...”), machines (“tools that do not require human energy input...”) and automata (“... machines that require neither human energy input nor immediate human direction”). These categories, with the possible exception of apparatus and utilities, are resonant with artefacts that learners design and make in design and technology classrooms.

Mitcham begins with an epistemological analysis of technology as **knowledge** with a taxonomy of increasingly conceptual distinctions: sensorimotor skills (acquired through heuristic or mimicry), technical maxims (including rules of thumb and recipes), descriptive laws (recognising cause and effect – if you do X then Y will happen), and technological theories (involving real world application of theory and/or operation of humans and technology). Mitcham draws parallels with Dreyfus' five stages of skill development: novice, advanced beginner, competency, proficiency, and expertise (Dreyfus and Dreyfus, 1986); although he goes on to infer that ‘knowing how’ (procedural knowledge) is a heuristic precursor to a higher level ‘knowing that’ (conceptual knowledge), a notion that Ryle (1949, 1990) and McCormick (1997) challenge.

Technology as **activity** can be viewed as the factor that unites knowledge and volition resulting in the production of technological objects (artefacts). Indeed technological objects, as tools in the ideation and

realisation process or the outcomes themselves, can likewise influence technological activity. Mitcham list typical behaviours in technological activity loosely as actions (crafting, inventing, and designing) and processes (manufacturing, working, operating, and maintaining). A further dimension to technology as activity is the distinction between useful (or servile) and fine (or liberal) arts, the names of which indicate the historic and cultural bias, elevating the fine (or use-less) arts. In technology as activity, it becomes clear that design and technology cannot lay sole claim on the domain of technology. Therefore the subject must articulate the unique perspectives and pedagogies that it lends to a broad and balanced curriculum and what dispositions it engenders; such as design “as a method of practical action” (Mitcham, 1994: 228-229) that underlies all practical activity (including business, education, law and politics).

In technology as **volition**, Mitcham moves the discourse towards philosophy and into the mind, motivation and intentionality. Interpretations of volition in technology are wide and varied, ranging from biological imperative to the competing drives for control and freedom. Mitcham quotes Ferré (1988) describing technology as “practical implementations of intelligence” (p.30) and the incremental improvements of this “embodied in culture and perpetrated by tradition” (p.36-37); positioning technological human activity as predating modern scientific notions and reconstructions. Mitcham describes volition as the most subjective of the modes of technology, expanding that one cannot directly know or perceive volition, relying on external action to infer the intention and character the actor.

Mitcham acknowledges that the four modes of technology overlap and interact. In this it is helpful to ask ourselves how this relates to design and technology as curricular entity. He exemplifies the interaction of technological object and activity (without knowledge and volition) as “play with toys” (p.269), and one could liken this to focused making activities in design and technology, which engage learners in the development of skills, as knowing how. In design & technology, technological volition and activity might result in speculative designing; to meet a perceived need or desire. Therefore, it is important to consider the breadth and complexity of technology in constructing not only a strong defence of the role of design and technology in the curriculum, but also in designing an appropriate curricular experience for the classroom.

## 6. SOCIO-TECHNOLOGICAL HUMAN ACTIVITY

The social constructivist view of human evolution and development acknowledges the intertwined nature of technology and society, and mediating artefacts as “objectifications of human needs and intentions” (Daniels, Cole and Wertsch, 2007: 255; Wartofsky, 1979; Vygotsky, 1978), akin to Mitcham’s aforementioned technological volition. Design and technology takes a holistic mind-body stance, as described by Kimbell, Stables and Green’s (1996) in their model of the dynamic interaction between head (thinking) and hand (acting) during designing and making activity. The dualistic worldview of Descartes that considers the mind and body as separate entities, privileging the mind over the body, has been challenged by Ryle (1949), Vygotsky and Dewey (Russell, 1993). Dewey and Vygotsky challenged reductionism and dualistic divisions within education and beyond, “denying all absolutes to assert a dynamic holism” (Russell, 1993: 173-174). Furthermore, Brunner (2009) builds on the cultural aspect of this holistic view of the “technical-social way of life” (p. 160) in human evolution.



*Figure 2. Möbius, representation of the dynamic interaction between technology and society*

The Möbius strip (Figure 2) provides an apt visual metaphor for the dynamic relationship between technology and society, avoiding the question of pre-eminence or causal nature of one over the other. That being said, emerging evidence from the study of the brain suggest a causal effect from the tool use to the development of



language (Johnson-Frey, 2004; Wolpert, 2003; Greenfield, 1991). Furthermore Tallis (2003), acknowledging the relationship between tools and language, cites fossil records as evidence of tool use predating capacity for speech and therefore a more convincing argument for the achievements of humans beyond our fellow hominids. The social achievements of modern humans, including the liberal arts, are facilitated by technology. For example, the painter does not normally paint without a brush (or other suitable implement), nor does the sculpture carve without the appropriate tools; both of which being technological artefacts, which have enabled artistic expression and the evolution of styles.

Campbell (2011) explores intelligence and the relationship between language use and tool use, identifying common features and the notion of a tool as an extension of the body. It may be that to talk about tools and language as different things is unhelpful, as the language extends the embodied mind to communicate with others through speech and writing. Writing as a cultural psychologist, Cole (1996) describes the example of a visual impaired person using a stick (white cane) and asks whether the sensation begins in the hand or in the stick. Nickerson (2005) discusses technology as a cognitive amplifier “either by facilitating reasoning directly or by reducing the demand that the solution of a problem makes on one’s cognitive resources, thereby freeing those resources up for other uses” (p.6). In this way people use technology “to outsource, or distribute, elements of cognitive capacity” (McLain, 2012: 334).

## 7. CONCLUSION

Through this paper we have explored the value of technology within society, how technological developments have helped to shape our evolution and society. We have also sought to locate the problem of design and technology as a subject in the curriculum with an undefined epistemological basis. First, through the lens of Bernstein’s classification and framing of educational knowledge, which explains the difficulty the subject has in defining what is uniquely design and technology knowledge. Second, through the lens Mitcham’s modes of the manifestation of technology, which explains the difficulty in defining technology. In this paper we begin to argue for design and technology education at the heart of the modern democratic curriculum as a cultural.

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# Girls' Engagement in Technology Education: A Systematic Review of the Literature

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The aim of this study is to review international published scientific literature on the subject of girls' engagement in technology education, in order to: (a) identify what is the most common descriptions of the relationship between girls and technology, (b) identify how girls' engagement in technology education is described, and (c) identify the type of technology concerned. After systematically searching a bibliographic database, 21 articles were located and included in the study. For each article, we have analysed the purpose of the study, the content of the research done, the research method used, and the sample characteristics and the results observed. The results of the literature review are discussed in terms of their implications for future research and can be used as guidance for educators and researchers in the area. This could lead to further questions, such as if a negative discourse around girls' relationship with technology may assist or hinder girls' engagement in technology and technology education.

*Key Words: Girls' engagement, gender, systematic review.*

## 1. INTRODUCTION

The close relationship between gender and technology, in structures, symbols, and identities, has long been acknowledged by feminists, although the feminine connection with technology has often been downplayed in public discourse. According to Cheryan, Ziegler, Montoya & Jiang (2016) factors including lack of confidence, lack of support at home, in the classroom or from other authority figures, and lack of peer support can explain why so few girls pursue a career in technology. Feminists scholars of technology (e.g. Harding, 1986; Cockburn & Ormrod, 1993) argue that everyday discourses of technology culture are a prominent factor that cause stereotyping and gender norms in a negative form. These norms fuel ideas of what technological agency is, and whose interest in technology and what kind of technology are regarded as legitimate (Wajcman, 1991).

There are thus deeply rooted structures in society that influence girls' engagement in technology from an early age. Specific attitudes and roles hinder girls' benefitting from the opportunities provided by technology education because technology is seen and presented as an exclusively male domain (Cheryan, Ziegler, Montoya & Jiang 2016; Turja, Endepohls-Ulpe, & Chatoney, 2009). Thus, there may also be a problem with the actual concept of a male, "nuts and bolts" technology and how it is taught in school. de Vries (2006) points out that girls are less confident than boys when handling so-called hard technology; computers, electronics and other similar artefacts. This lack of confidence extends to the use of what can be identified as hard technology even in the school (Kimbell, Stables, & Green 1996). Cheryan, Ziegler, Montoya & Jiang's (2016) meta-study shows that certain teaching methods may favour boys over girls. Sadker and Sadker (1994) elaborate on teaching methods by showing that teachers may inadvertently favour boys, especially in areas that society considers to be in the male domain, by providing them with more and better instruction.

These two problematics – the construal of technology and technology education as male domains, and a corresponding narrow concept of technology – are highly relevant to address for the research field of

technological education, and attending to them can even be seen as a competence in teaching technology. In the end, knowledge about reasons for the existence of gender stereotypes can support girls' engagement in technology education. The aim of the study is to identify what is the most common descriptions of the relationship between girls and technology, how girls' engagement in technology education is described, and what type of technology it concerns, by systematically reviewing the research literature in the area of girls and technology education. The study engages in a critical content analysis of the discourses about girls and technology within the existing literature on girls and technology education. We conclude by presenting a synthesis of the existing empirical evidence.

## **2. METHODS FOR COLLECTING AND ANALYSING DATA**

A systematic literature review is a method that enables the evaluation and interpretation of all accessible research relevant to a research question, subject matter or event of interest (Kitchenham, 2004). This systematic literature review focuses on international studies researching girls' engagement in technology education. The term "discourse" has become one of the key terms in the vocabulary of the humanities and the social sciences. It has been the subject of discussion and has different meanings in different contexts. In this study, however, we use Petrina's (1998) description of the concept and hence discourse refers to "recurrent statements, themes and wordings across texts, which represent orientations to the world" (Petrina, 1998, p. 30). In the present context, "texts" refers to research articles.

To conduct this review, we followed a process for conducting systematic reviews based on Kitchenham (2004) and covering the following stages and activities:

Stage 1: Planning the review

Activity 1.1: Identification of the need for a review

Activity 1.2: Development of a review protocol

Stage 2: Conducting the review

Activity 2.1: Identification of research

Activity 2.2: Selection of primary studies

Activity 2.3: Study quality assessment

Activity 2.4: Snowball sampling

Stage 3: Reporting the review

Activity 3.1: Communicating the results

### ***2.1 Planning and conducting the review (Stages 1 and 2)***

Initially, a search was conducted to identify the existence of research literature studying girls' engagement in technology education. Within the context of this paper, we carried out a systematic literature review using the basic approach identified in Kitchenham (2004), in order to examine the state of research on girls' engagement in technology education, based on the following research questions:

Question 1 (Q1): What is the most common descriptions of the relationship between girls and technology?

Question 2 (Q2): How is girls' engagement in technology education described?

Question 3 (Q3): What type of technology is described?

#### *Activity 2.1.1: Identification of research*

For the purposes of this study, data was collected in January 2018, in the following international online bibliographic database: ERIC (Educational Resources Information Centre). Searches were limited to full texts in peer-reviewed international high-quality journals, written in English, and published between 2000 and 2017 (research over the last 18 years). The specific protocol executed in the ERIC database was: Find all my search terms: girl AND interest AND technology AND education. The results of the data collections were thus initially 117 articles. The articles were cross-referenced in Web of Science to guarantee the scientific quality of each article. The decision on using the temporal limitation of the period 1 January 2000 – 31 December 2017 was made to achieve a larger sample, but also because there may have been changes in discourse over time.

*Activity 2.1.2: Selection of primary studies*

The following criteria (inclusion criteria, IC) were used to determine which papers would be included in the review:

IC1: The article reports on research about girls’ engagement in technology education.

IC2: The article presents a discussion about girls’ engagement in technology education.

Articles were included only if both these criteria were met.

Five criteria for excluding (EC) articles were also identified:

EC1: Afterschool activities. We wanted to examine technology during the school day.

EC2: Science education. We wanted to look specifically at technology education studies.

EC3: ICT Education or use of ICT tools and educational technology. Excluded for being a tool for learning technology and not being the subject of technology specifically.

EC4: Computer science. Excluded when handling the computer was in focus, and not technology *per se*.

EC5: Age span outside 10 -17-year-olds.

Initially the limitation “elementary” was included in the research. Applying this limitation resulted in only three articles. By excluding the word “elementary” from the search we got a larger scope of included articles and it resulted in a broader variation of technology education studies from a variation of countries. Furthermore, elementary does not entirely match the ages 10-17 because they also overlap with secondary education. To be able to include the age span we wanted to examine, we therefore manually excluded all articles fulfilling exclusion criterion EC5, Age span outside 10-17-year-olds. We wanted to look specifically into ages 10-17 because this is an age that research (e.g. Sinnes & Løken, 2014) has pointed out as particularly formative for girls’ engagement in technology education.

The initial search thus generated 117 international peer-reviewed research papers. In the first stage, we analysed titles and abstracts with regard to the inclusion (IC1-2) and exclusion criteria (EC1-5), and subsequently 21 studies finally matched our full search criteria based on the research questions.

*Activity 2.3: Study quality assessment*

The data is a fairly condensed assortment taken from a large number of publications published during eighteen years. As can be observed in Table 1, approximately 82% of the total number of research articles were excluded based on IC1-2 and EC1-5.

**3 RESULTS (STAGE 3) AND DISCUSSION**

*Activity 3.1: Communicating the results*

*Table 1. Results of the final sampling, in relation to the research questions*

Article	Q1. What is the most common descriptions of the relationship between girls and technology?	Q2. How is girls’ engagement in technology education described?	Q3. What type of technology is described?
Ardies, J., De Maeyer, S., & Gijbels, D. (2015).	Insufficient representation of girls and women in STEM fields: ‘[-] girls are needed in technical studies and professions, as the relative number of students in technology-related studies has been decreasing in most industrialised countries’ (p 366).	Not defined. But described as an attitudinal factor.	Not defined.
Article	Q1. What is the most	Q2. How is girls’ engagement	Q3. What type of technology is

	<i>common descriptions of the relationship between girls and technology?</i>	<i>in technology education described?</i>	<i>described?</i>
<i>Ardies, J., De Maeyer, S., Gijbels, D., &amp; van Keulen, H. (2015).</i>	<i>'girls are more negative toward technology' (p 46).</i>	<i>Interest in technology defined as a measure for ones feeling of wanting to know or learn about technology.</i>	<i>Not defined.</i>
<i>Mammes, I. (2004).</i>	<i>'Women are clearly reluctant to participate in courses of studies for natural sciences or technology even though these subjects have gained greatly in importance since the beginning of the twentieth century' (p 89).</i>	<i>Defined as a person's interest in technology.</i>	<i>Christmas tree - components of the electrical circuit.  Designing and making a nesting-box.</i>
<i>Autio, O., &amp; Soobik, M. (2017).</i>	<i>'not a surprise that boys and girls differ in their interests, the difference is usually emotionally charged' and 'possible reason for this might be the different social expectations for boys and girls' (p. 201).</i>	<i>Not defined but claims "boys' and girls' different interests and earlier experiences obviously have an impact on motivation for learning about technology" (p. 193).</i>	<i>Technology can be described by means of how humans modify the world around them in order to meet their needs and solve practical problems (p. 195).</i>
<i>Colette, A., &amp; Chatoney, M. (2017).</i>	<i>As a social construction. 'Furthermore, the social and cultural distribution of activities between men and women can also lead to a gendered vision of technical objects according to their predominant users' (p. 5).</i>	<i>Not defined.</i>	<i>Not defined but examines different artifacts. 'Thus, we see that a certain number of typically male objects (crane, range servant boy, balloon...). The same applies to rare items typically feminine (tablecloth, pastry molds, pan...)' (p. 15).</i>
<i>Osagie, R. O., &amp; Alutu, A. N. (2016).</i>	<i>'This study shows that there is strong evidence that the culture discourages girls' (p. 234).</i>	<i>Not defined.</i>	<i>Not defined.</i>
<i>Stevanovic, B. (2014).</i>	<i>As an insufficient representation of girls and women in STEM fields due to the effect of educational policy and information campaigns on parents, teachers, guidance staff and girls.</i>	<i>Not defined but presume that personal, contextual and social cognitive factors have an impact on the formation of interest (p. 553).</i>	<i>Not defined.</i>
<i>Chatoney, M., &amp; Andreucci, C. (2009).</i>	<i>'certain contents, certain types of activities, certain forms of studies, certain gestures of education and scholastic shapes are better adapted to the girls than to the boys and conversely' (p. 393).</i>	<i>Not defined.</i>	<i>The concept of technology is not defined but task performed in the study was a product improvement of a Mini football cage and a jewellery box.</i>
<i>Article</i>	<i>Q1. What is the most common descriptions of the relationship between girls and technology?</i>	<i>Q2. How is girls' engagement in technology education described?</i>	<i>Q3. What type of technology is described?</i>

Rasinen, A., Virtanen, S., Endepohls-Ulpe, M., Ikonen, P., Ebach, J., & Stahl-von Zabern, J. (2009).	As an insufficient representation of girls and women in the field: 'there are still remarkable gender differences in the number of males and females studying and working in the technological fields' (p. 368).	Not defined.	Not defined. Study is a German – Finnish curriculum analysis.
Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017).	As an insufficient representation of girls and women in STEM fields: 'Women hold a disproportionately low share of STEM undergraduate degrees, particularly in engineering' (p. 151).	Not defined.	Not defined but electric circuits were used in the performed task.
Master, A., & Meltzoff, A. N. (2016).	'Sociocultural stereo- types associating STEM with males act as barriers that prevent girls from developing interests in STEM' (p. 215).	Not defined.	Not defined but programming a robot using a smartphone was one described task. Another task was constructing a Lego robot.
Shoffner, M. F., Newsome, D., Barrio Minton, C. A., & Wachter Morris, C. A. (2015).	'the importance of relationships and connectedness to identity development in girls and young women' (p. 111).	Not defined but outcome expectations are described as important factors in the development of youth's interests in and goals toward future careers.	Not defined. Article about science, technology, engineering, and mathematics (STEM).
Chang, S., Yeung, Y., & Cheng, M. H. (2009).	'girls have more experience related to S&T than boys, but not feel interested in learning S&T' (p. 454).	Not defined but are described as learning interests.	Not defined.
Voyles, M. M., Fossum, T., & Haller, S. (2008).	The problem of women not pursuing careers in technology. Factors other than personal preference discourage women from entering STEM fields.	Not defined.	Not defined but task performed in study was building and programming a Lego Mindstorms robot.
Villas-Boas, V. (2010).	Must awaken an interest in technological knowledge: 'Unfortunately, most girls do not consider a career in these fields, in which females are under-represented. The problem starts early, with society stimulating girls to take an interest in subjects said to be 'feminine' rather than 'masculine' (p. 294).	Not defined.	Not defined.
Fensham, P. J. (2009).	Girls as not engaging in technology education.	Not defined.	Not defined.
Article	Q1. What is the most common descriptions of the relationship between girls and technology?	Q2. How is girls' engagement in technology education described?	Q3. What type of technology is described?



<i>Virtanen, S., Rääkkönen, E., &amp; Ikonen, P. (2015).</i>	<i>Girls as lacking in the field of technology.</i>	<i>Interest in this context refers to choosing something among alternatives or favouring something over its alternatives (p. 200).</i>	<i>Not defined but discussed from the Finnish Curriculum.</i>
<i>Autio, O., Soobik, M., Thorsteinsson, G., Olafsson, B. (2015).</i>	<i>Not expressed.</i>	<i>Not defined.</i>	<i>Technology is determined and guided by human emotions, motivations, values, and personal qualities (p. 96).</i>
<i>Jennings, S., McIntyre, J. G., &amp; Butler, S. E. (2015).</i>	<i>Girls appear to be less interested in STEM than boys.' Interactions between gender and age influence the consideration of engineering as a possible career' (p.15).</i>	<i>Not defined.</i>	<i>Not defined but understood as engineering.</i>
<i>Autio, O., Olafsson, B., Thorsteinsson, G. (2016).</i>	<i>Focus on the insufficient representation of girls and women in STEM fields.</i>		<i>Not defined.</i>
<i>Dakers, J. R., Dow, W., McNamee, L. (2009).</i>	<i>Societal impacts on why girls do not engage in technology. Interest as construction.</i>	<i>Not defined.</i>	<i>Not defined.</i>

In this section, we discuss the results of the systematic review, in an attempt to answer the three research questions Q1 – Q3 (elaborated in Stage 2). Regarding Q1 – What is the most common descriptions of the relationship between girls and technology? – the analysis of the discourses shows that adjectives like “negative”, “reluctant”, “insufficient”, “discouraged”, “lacking”, etc. are connected to the female relationship with technology. Many studies couple these kinds of descriptions with the underrepresentation of girls and women in STEM fields, which also includes technology education. So, in a sense, in response to Q1 girls and women are seen as lacking in and disconnected from, but also desirable in, STEM fields. Most studies venture some kind of explanation for this but none give the personal preferences of women as the reason; these studies instead point to expectations and factors in the broader societal realm: teachers, schools, or education policy/curricula. It seems that one of the problems is a dominating male code, and that women are more interested in feelings, relationships, and connectedness. As regards Q2 - How is girls’ engagement in technology education described? – there are few if any descriptions of this in the reviewed articles, other than that boys’ and girls’ interest are different. Girls’ interest is, in fact, described in some studies, for example, the PATT studies by Ardies et al. (2015a, b). Girls are considered less interested in technology than boys, according to these studies. In response to Q3 – What type of technology is described? – few articles define the concept of or type of technology, although those studies that do define a type of technology either put forward a neutral, or male kind of “nuts and bolts” technology. Exceptions are Chatoney & Andreucci (2009), who refer to a jewellery box, and Colette & Chatoney (2017) who take up examples of both what can be considered as male and female artefacts.

Our analysis of the data about girls’ engagement in technology was aggravated by scarce information in the reviewed articles (see Table 1). However, by posing Q1, Q2 and Q3 and applying an analysis of these discourses we have yet revealed some structures, symbols, and identities prevalent in the research of gender and technology. To some extent, the research reveals a traditional view of what technology is – a concept of technology and empirical examples of types of technology with a typical male, nuts and bolts code. Questionnaires, for example, could contain questions that prompted the following remark: ‘Spends a lot of time with engineering-related hobby activities’ (Autio et al., 2016, p. 98) which can be seen as a male-coded form of technology. This might create misleading answers from girls that do not identify their engagement in technology as engineering. When revisiting the PATT questionnaire, Svenningsson et al. (2018) also discovered that the gender category cannot be used as intended since it might be gender-biased. There thus seems to be a mismatch between the image of girls as not engaged in technology and that of expecting them to be engaged in technology, although most of the studies in the sample acknowledge that the reasons for this

disengagement are beyond girls' and women's control. However, gendering that takes place within a research discourse seems to be complex as well as conflicting, which invites further more detailed empirical research.

The study may contain limitations that can affect the ability to draw conclusions or infer results beyond the scope of the study. Use of other variables and samples can be found to affect the results in different directions. This study should only be seen in the context it is in, since the study only considers a few variables.

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# Teacher Students' Critical Thinking Skills Using the Concept of Disruptive Technologies

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Critical thinking is fundamental to 21st century learning and has thus become an important part of the technology curricula in many countries. Critical thinking draws on the ability to examine, analyse, interpret and evaluate, as well as asking questions and participating in discussions about risks and benefits of different technological solutions. An important task for teachers is to support young children in developing these skills. Students on a Swedish primary school teacher education programme were given an assignment inspired by the concept of 'disruptive technologies' (Barlex, Givens & Steeg, 2016; Manyika, Chui, Bughin, Dobbs, Bisson & Marrs, 2013), choosing from one of nine disruptive technologies and searching for information. The list was created on the grounds that these are technologies that are likely to have a significant effect on the students' lives in a not too distant future. Based on the information found, the students were to critically analyse the technology they had chosen. This case study was performed through a thematic analysis of 120 assignment texts. The analysis showed that some of the suggested technologies were chosen more often than others. Autonomous cars came top, although robots in elderly care were the most frequently chosen technology among female students. The students performed well in the searching and collecting process. They found information about pros and cons for their chosen disruptive technology. However, the analysis also showed that the students had difficulty evaluating and problematising the information they had found. In their conclusions they did not change their original point of view. Even though they found more negative aspects of a new technology, they accentuated the positives.

*Key Words: Technology education, Critical thinking, Technological literacy, Disruptive technologies, Teacher students.*

## 1. INTRODUCTION

There is growing concern about whether today's learners possess the combination of critical thinking, creativity, and collaborative and communication skills necessary to be able to tackle the unexpected developments they will face in the future (Scott, 2015). Due to the emergence of increased attention to the competences required for the knowledge society, especially digital technologies, there is a call to update educational systems (e.g., European Commission, 2018; Voogt & Pelgrum 2005). Educators, as well as representatives of education ministries, governments, foundations, employers and researchers, often refer to these abilities as *21<sup>st</sup> century skills* (Scott, 2015). But even if the term is widely used, there is no single framework for what it means or what knowledge is required for these skills (Anandiadou & Claro, 2009). However, from an analysis of curriculum and assessment frameworks for 21st century skills around the world, some of the most frequently named skills are communication, creativity, critical thinking and problem-solving (see e.g. Care, 2018; Binkley, Erstad, Herman, Raizen, Ripley, Miller-Ricci & Rumble, 2012; Voogt & Roblin, 2012).

Even if it is difficult to predict what knowledge and skills future generations will need, we can assume that technological literacy implies that both today's and future citizens are able to make well-informed, wise judgements about various aspects of technology, and to compare evidence, evaluate competing proposals and make responsible decisions. Without this kind of knowledge they will not be able to make deliberate democratic choices (Garmire & Pearson, 2006; Keirl, 2006).

From a technology education perspective, it is clear that education cannot be expected to teach students how all contemporary (or future) technologies work. That means that a 21<sup>st</sup> technological literacy involves more than the ability to create technological objects or to use or understand the function of certain technologies – students

also need to develop their critical thinking skills and be open to seeing the technological world from multiple perspectives (Axell, 2017a; 2017b; Dakers, 2011; Petrina; 2000; Williams, 2009).

### **1.1. Technological Literacy and Critical Thinking**

The aim of the school subject of technology is that students learn to understand and act in a responsible way in the technological culture they are a part of. Due to the ubiquity of technology, an understanding of what it is, how it is created, and how technological choices shape society as a whole, is important for democratic and well-informed citizenship. How well citizens are prepared to make these choices depends largely on their level of *technological literacy*. According to Garmire and Pearson (2006), technological literacy can be described as having three major dimensions: 1) *knowledge*, 2) *capabilities*, and 3) *critical thinking* and *decision-making*.

However, even if the concept of ‘critical thinking’ is widely used within educational discourse, there is no uniform framework for what it means or what knowledge is required for these skills (Anandiadou & Claro, 2009). Nevertheless, Ennis (2018), a leading researcher on the concept, describes critical thinking as a “reasonable reflective thinking focused on deciding what to believe or do” (p. 166).

What characterises a person with highly developed critical-thinking and decision-making skills is, according to Garmire and Pearson (2006), that when “confronted with a new technology, he or she asks questions about risks and benefits and can participate in discussions and debates about the uses of that technology” (p. 2).

Dakers (2011) agrees with Garmire and Pearson when he states that to be able to create conditions of understanding for the modern technological world we live in, the technology curricula in many countries must place more emphasis on issues relating to values and attitudes in terms of technology, such as ethics, environmental impact, social impact, sustainability, and the interface between humans and their active involvement with technologies. Dakers’ conclusion is that a more philosophically oriented pedagogical framework is thus needed.

Petrina (2000) also emphasises the importance of a critical perspective in technology education. He calls for the development of a *critical technological literacy*, which he describes as “a critical engagement with, and appropriation of, the built world and its signs of the times, the use of critical discourses, genres, or language to confront that world, and the mobilisation of resources to politically transform what’s built” (Petrina, 2000, p. 201).

However, this is a challenge since the main focus of technology education still tends to be on developing knowledge relating to the fabrication of artefacts, and not on developing a critical awareness of the technological world young people inhabit; how it shapes their lives and will shape them in the future (Dakers, 2006). Additionally, previous technology education studies show that many students lack the ability to make a critical assessment of technology and rather act as spectators or uncritical consumers of technology (de Vries, 2005).

### **1.2. The Swedish Context**

As a part of ‘the waves of change’ in education, the Swedish Government commissioned the National Agency for Education in 2015 with drawing up guidelines for an updated national strategy for the Swedish school system. One part of this work was to revise the curriculum for primary and upper secondary education. In the revised curriculum (2017), digital competence is visible throughout the curriculum, but is explicitly formulated in some specific subjects: technology, mathematics and social studies (Heintz, Mannila, Nordén, Parnes & Regnell, 2017; Swedish National Agency for Education, 2017). Under the heading “Fundamental values and tasks of the school”, it is stated that schools should help students to develop an understanding of how digitisation affects the individual and societal development (Swedish Agency of Education, 2017, p. 9). In line with the changes in the curriculum, teacher education courses are undergoing revisions.

Based on these revisions, the aim of this case study was to examine teacher students’ critical thinking skills by examining an assignment on the concept of ‘disruptive technologies’ (Barlex, 2017; Barlex, Givens & Steeg, 2016; Manyika, Chui, Bughin, Dobbs, Bisson & Marrs, 2013). Barlex (2017) justifies the concept in

technology education by stating that it is important for young students “to engage in critique of technology particularly with regards to those technologies that might have a significant effect on their lives” (p. 233).

The participants originated from two student groups: the undergraduate programme for teaching in preschool class and grades 1-3, and students from the undergraduate programme for teaching in grades 4-6. The technology course is mandatory for students studying to teach preschool class and grades 1-3, while the technology and science courses are elective for students studying to teach grades 4-6.

## **2. METHODS FOR COLLECTING AND ANALYSING DATA**

### **2.1. A Description of the Assignment**

As an introduction to the assignment, the teacher students were told that there is often a reliance on new technology, especially among young people. The things we call technologies are ways of building order in our world – they are powerful forces that give meaning and direction to our lives. Power conditions, authority, freedom and social justice are often deeply embedded in technical devices and systems (Winner, 1986). When a new technology emerges, it opens up new possibilities for human activity and interaction. Although it may not be immediately apparent, some technologies have a huge impact on society and noticeably change people’s activities and interactions. Such technologies can be described as ‘*disruptive technologies*’ (Barlex, 2017; Barlex et al., 2016; Manyika et al., 2013).

The students were then given the task of choosing one of nine technologies categorised as ‘disruptive technologies’ and searching for information. The list was created on the grounds that these technologies are connected to digitisation and are likely to have a significant effect on the students’ lives in a not too distant future. This was an individual written assignment, and the students were asked to choose one of the following technologies:

- The ‘My Doctor’ app
- ‘Swish’ (A Swedish mobile payment system)
- Autonomous cars
- Electric cars
- Drones (civil and military)
- The Internet of Things
- Wrist chips
- Robots in elderly care
- Digitisation of education

Based on the information found, the students were asked to critically analyse the specific disruptive technology they had chosen. The different steps of the analysis were based on Barlex et al.’s (2016) Teacher’s Guide and the McKinsey Global Institute’s descriptions of ‘disruptive technologies’ (Manyika et al., 2013) .

The first step was to discuss the chosen technology based on four criteria:

- It “upset the status quo”
- It changes the way people live and work
- It reorganises financial and social structures
- It leads to entirely new products and services

The next step was to put the specific technology at the centre of a “winners and losers target chart”. The individuals or groups that are directly affected by this technology should be placed in the first circle, and those indirectly affected in the second. The students were also asked to identify ‘winners’ and ‘losers’ among those affected and colour them in two different colours, describe them and explain why they were designated thus.

They should then take a stand: first argue from the perspective of the ‘winners’, and then argue for the ‘losers’. This should end with a final analysis of the chosen technology, including the following perspectives: historical, gender, sustainable development, societal and global perspectives.

The final step was to write a suggested application of the idea of ‘disruptive technology’ for primary education (ages 6-12). What kind of disruptive technology can be subject to analysis in a primary technology classroom? How could the ‘disruptive technology’ approach be used in the classroom? Why is this specific ‘disruptive technology’ a good choice for an analysis with children?

## 2.2. The Analysis

Barlex, Givens, Hardy and Steeg (2016) used the concept of ‘disruptive technologies’ in a case study with trainee teachers. Their focus was on the students’ ability to identify whether a technology was disruptive (Manyika et al., 2013). Our students were also asked to argue for the disruptiveness of their chosen technology, but our focus was on their ability to identify and analyse ‘winners’ and ‘losers’ connected to the application of a chosen technology.

The study was performed through an analysis of the students’ assignment texts and based on Braun & Clarke’s (2008) description of the thematic analysis process, which includes the following steps: reading and re-reading texts, systematically coding, searching for themes, defining themes, and finally summarising the patterns found and discussing the themes identified in relation to the aim of the study.

However, although all the assignments were analysed, in this case study we only present the results of the thematic analysis of the most frequently chosen topics for female and male students.

## 3. RESULTS

### 3.1. Topic chosen

Our analysis shows that the students found some topics in the list more interesting than others.

Topic chosen by (n)	Male students (18)	Female students (102)
Autonomous cars	37%	20%
Robots for elder care	5%	33%
Digitisation of education	26%	12%
Drones	11%	5%
Swish cell phone pay service	5%	6%
Electrical cars	5%	5%
Microchip implants	0%	14%
Internet of Things	5%	0%
My Doctor Online	0%	5%

Since autonomous cars were the most frequently chosen topic by both female and male students, we chose to carry out a thematic analysis of their responses. Through our analysis, we identified two overarching themes: *contradictions* and *over-reliance on technology*. Within these themes, we also identified a selection of sub-themes, illustrated here with quotes from the students’ texts:

### 3.2 Contradictions

Economic aspects

“Producers of cars and car rental companies are winners”

“The cost of transportation will be lower for individuals”

“More people will be able to go by car”

“The number of cars will be greatly reduced”

“Professional drivers will lose their jobs”

“There will be many jobs for programmers and engineers”

Environmental aspects

“The number of cars will be greatly reduced”  
“More people will be able to go by car”  
“The cars need no parking spaces – they will circulate”  
“When there is no need for parking spaces, there will be more green areas and parks”  
“Autonomous cars are good for the environment, as people will be able to co-travel”  
“Kids can use these cars by themselves”

#### Social impact

“We will have more time for social activities with family and friends”  
“Children can transport themselves to school and leisure activities”  
“Elderly and disabled people will be able to travel by themselves.”  
“Elderly and disabled people are dependent on help from others/a driver when travelling by car”  
“There are more negative aspects than positives of autonomous cars in the information found, but the positive aspects outweigh the negatives anyway”

### 3.3. *Over-reliance on technology*

#### Lack of risks

“Autonomous cars are designed not to crash into people or things – they are safer than human drivers”  
“The sensors in combination with AI make it impossible for these cars to crash”  
“You can go by car with other people who are going to the same place”

#### The perfect technology

“The autonomous cars can be hacked – but that problem will be solved by safer systems”  
“Responsibility in case of an accident is a problem – the laws have to be changed”  
“Automated cars have 30 sensors, which means they can make the best decisions”

## 4. DISCUSSION

Based on our analysis, we note that some of the suggested technologies were chosen more than others. Autonomous cars came top, although “robots in elderly care” was the most frequently chosen technology among female students. Male students were more interested in the technology itself and female students in safety, health and the individual impact of a new technology. As previously noted, Sweden is about to change its national curricula and will have more digital competence, computer science and programming from grades one to nine, and this was also met with high interest by the students.

The students usually worked well in the searching and collecting process, and found information about the pros and cons for all their topics. They also mentioned the sources they used, and to some extent were alert to alternatives, and able to identify risks and benefits (Ennis, 2018; Garmire & Pearson, 2006).

What the students found difficult, however, was critically analysing, problematising and evaluating the information they had found. For example, they did not change position even if the evidence or reasons were insufficient (Ennis, 2018). Their conclusions seemed to be their original point of view. Even if they found more negative aspects of a new technology, they accentuated the positives. In their conclusions, they referred in particular to:

*Efficiency:* Autonomous cars would make “stressful everyday life” easier: things would be faster, smoother and less expensive, and people would have more time “to do other things”.

*Equality:* More people will be able to use cars, for example children and disabled people. Gender was mentioned, but in the argument that since there is a perception that women are inferior drivers, autonomous cars will contribute to more gender equality, since no one will be driving a car.

*Security:* The autonomous cars are safer than human drivers, since cars controlled by robots “cannot crash”, and the danger of tired drivers or drivers affected by alcohol would disappear. The danger of hacking was



discussed, but the conclusion was that this is a problem that will be solved by engineers. Ethical and moral problems related to accidents would also be solved by engineers – the cars “will be programmed to be ethical”.

Environmental arguments were used by almost everyone, sometimes with a naive belief that traffic volumes would be greatly reduced and that a fleet of cars always moving around would be climate friendly. Almost all students were very confident that technology will never fail. Even though they read articles discussing problems with software bugs and possible sensor failures, they strongly believed that “the car is designed not to crash”.

We do not know why the negative aspects that the students identified had so little impact on their conclusions, but some possible explanations could be:

- 1) A general reliance on technological development: they view technological development as autonomous, i.e. it ‘lives’ its own life and is something that they as citizens can have little or no impact on.
- 2) The students do not differentiate between the credibility of different sources. Popular journals, news media and information from YouTube, radio and TV shows and scientific papers were mixed and given the same value in their analysis. Maybe they understood their task as simply collecting and showing, like a scientific review of what had been written about the topic chosen.
- 3) The students thought they were expected to ‘please’ – if they participate in a course in technology, they are expected to have a positive attitude towards all kinds of technology.

In relation to critical thinking and technological literacy (Dakers, 2011; Garmire & Pearson, 2006; Petrina, 2000), it was clear that the students did not have the skills to analyse the technology from a wider societal perspective or critically analyse the driving forces behind technological change. For example, very few students had a system view of the consequences of a world with autonomous cars. Philosophical discussions about ethics and morality (Dakers, 2011; de Vries, 2005) were also conspicuous by their absence.

In summary, the students’ texts can be interpreted as expressions of a deterministic view of technology, as expressed by one student: “The losers are those who do not follow the development.”

## 5. CONCLUSIONS

To summarise, the task was very much appreciated by the students – they put a lot of time into the task and wrote long reports. However, due to the results of this study we will make some changes in the course design. The students will be able to learn more about technology failures; components, sensors, software bugs and computer hacking. Likewise, we are considering using a more philosophically oriented framework (Dakers, 2011; de Vries, 2005). We will also try some of the ideas Barlex et al.(2016) propose, for example making the students identify with an individual using or trying to use a new technology: An elderly person without a smartphone in an online society, a blind boy in front of the McDonald’s self-ordering console, and other similar situations. By taking the role of an individual, they may be able to take a stance. Letting them write a dramatic show or make a video is another way of examining their findings. We are also considering cooperation and integration with subjects like drama and language. A debate where students argue for or against a specific technology might make them analyse and problematise what they have read, since they have to counter other students’ arguments.

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# Investigating T/E Design Based Learning: Student Ability to Select and Utilize STEM Content and Practices

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Competitiveness in the 21st century global economy ultimately depends on people literate in science, technology, engineering and mathematics (STEM) and who possess the knowledge and abilities requisite to solving complex technological problems. Researchers argue that integrative STEM education (I-STEM ED) actively engages students in technological/engineering design-based learning (T/E DBL) and is effective in promoting critical thinking (CT) skills necessary for complex problem solving (PS) (Cajas, 2001; Wells, 2010, 2016a-c). Pedagogically, T/E DBL intentionally promotes key CT and PS abilities leading to deeper understanding of the inherent STEM disciplinary connections requisite to designerly thinking (Lead States, 2013; Wells, 2017). However, in K-12 education T/E DBL is not intentionally taught or assessed for promoting CT/PS abilities. Assessment of CT/PS typically focuses on the extent of correctness in responses, and rarely on the reasoning that precipitated it (Docktor & Heller, 2009; Shavelson, Ruiz-Primo, Li & Ayala, 2003; Steif & Dantzler, 2005). Furthermore, the knowledge assessed relates directly to content taught in the classroom, and is devoid of the need for learners to demonstrate their CT and PS abilities. Herein lies the gap between preparing 21st century STEM literate individuals and the instructional approach of K-12 STEM education. The research presented investigates the extent to which students immersed in an I-STEM ED program used CT/PS skills to achieve a viable solution for an authentic design-based challenge when presented outside the context of the classroom in which their STEM content was learned. Five specific student abilities (SAs) contributing to authentic PS were identified and assessed following student engagement in a design-no-make challenge. Analyses indicate students performed significantly better in designing a solution compared with a hypothesized mean for students in a traditional classroom. Furthermore, the specific student abilities associated with selecting/utilizing relevant science and math content/practices, and communicating logical reasoning in their design solution were found to be critical to successful problem-solving.

*Key words: Design-Based, Authentic Problems, T/E DBL, Critical thinking, Problem-Solving, Student abilities*

## 1. MOTIVATION

The rapid pace of change, the complexity of human problems, and the ease of global access to technologies and human resources have created the demand for individuals well prepared to utilize their knowledge of science, technology, engineering and mathematics (STEM) in collaboration with professionals from diverse disciplines to solve complex novel problems. The European Commission for New Assessment Tools for Cross-Curricular Competencies in the Domain of Problem Solving (NATCCC-PS) brought together various experts in 2000 to establish appropriate definitions for the required student competencies in the 21st century (NATCCC, 2000). These experts agreed that critical thinking (CT) and problem solving (PS) were cross curricular competences (CCC) required within the context of increasingly complex sociocultural demands. In recognizing the relationship between CT/PS and sociocultural needs, their charge to education writ large was preparing students able to meet the demands of their complex technological world. One key conclusion drawn by the committee was that learning to problem-solve required competence “within and between several subjects” (p. 14); i.e., transdisciplinary competence. Preparing individuals who possess sufficient transdisciplinary competence is of

great importance for meeting tomorrow's sociocultural demands. However, evidence suggests that progress in doing so is hampered by most practitioners who still interpret the integration of STEM as simply meaning an increased emphasis on their silo discipline and who continue to teach adhering to a mono-discipline pedagogy (Wells, 2013, 2016).

Preparing learners to succeed in their chosen postsecondary STEM disciplines is dependent upon a clearly articulated curricular framework and definition for achieving STEM literacy: the ability to use content knowledge and skills in science, technology, engineering and math in solving human problems in a collaborative manner (NRC, 2009, Wiggins and McTighe, 2005). Literacy as defined within these individual disciplines is the ability to understand information or claims in the context of those disciplines, evaluate the validity of the same, and, communicate evaluations and predictions with a vocabulary that is consistent within those disciplines (NGSS Lead States, 2013; NCTM, 2000). Defining literacy from within a mono-disciplinary context promotes the misconception that literacy in one discipline is separate from that in another. This notion of artificially separating disciplinary literacy is not representative of authentic or real world situations where individuals are challenged to devise solutions or solve problems requiring knowledge at the intersections of STEM disciplines (NATCCC, 2000; Pope, Brown and Miles, 2015). Regardless of their postsecondary goals, for students to succeed in their increasingly complex technological world they must possess key CT/PS abilities that enable them to function within the continuum of disciplinary demands. Preparing such individuals able to meet the cognitive demands for solving complex problems necessitates that STEM education be intentionally integrative in its approach (Huber & Hutchings, 2004) and facilitated by T/E DBL pedagogical strategies requiring solutions within complex problem scenarios (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Barak & Assal, 2016; Wells, 2017).

T/E DBL as an instructional strategy is unique in naturally imposing inherent cognitive demands necessary for achieving a viable solution to complex design problems. These inherent demands are what is believed to require the learner to use key CT skills as a means for making informed decisions (PS skills) leading to viable design solutions. However, thus far little empirical research is available that documents the validity of T/E DBL for promoting the use of CT/PS skills while engaged in authentic design challenges. The research presented in this paper was conducted within a high school Governor's STEM Academy located in the mid-eastern part of the USA employing the Integrative STEM Education pedagogy. The research aim was to empirically demonstrate the correlation between student engagement in T/E DBL and the extent to which key critical thinking and problem solving abilities are used in arriving at a viable solution for an authentic T/E design challenge. Specifically, within the context of a high school Integrative STEM Education program, the aim was to provide evidence that the T/E DBL pedagogical approach is a viable instructional strategy for enhancing key critical thinking and problem solving abilities through engagement in authentic T/E design challenges.

## **2. THEORETICAL FRAMEWORK**

### ***2.1 Integrative STEM education (I-STEM ED) Pedagogical approach***

Integrative STEM Education (I-STEM ED) is the use of technological/engineering design-based learning (T/E DBL) to teach T/E content and practice, and to intentionally teach other targeted STEM content/practice inherent within the design of the solution. When effectively employed, this pedagogical approach promotes active learning through design challenges within an environment of structured student discovery. This environment provides the context for the challenge, along with the impetus for learning and utilizing science and mathematics content/practices through design of a solution, guided by the instructional intent for fostering active construction of understanding (habits of mind) through concrete experiences (habits of hand) (Wells, 2016b, p. 15).

The T/E DBL approach engages students in a design challenge that is the focal point for students. Design, a process that is inseparable from innovation, is a collaborative activity within which a group of people tackle an ill-defined (or authentic) problem that is constrained by resources available and real-world conditions. Most problems in life are ill-defined and can have multiple solutions (Ormrod, 2012). The best solution involves the optimization of constraints and benefits. For students, construction of knowledge occurs within the relevant

context of the design challenge, the culture of peer-to-peer questioning and researching in a collaborative environment (Brown, Collins & Duguid, 1989; Bransford, Brown & Cocking, 2000).

This student-centered instructional style has been found to be superior to the traditional teacher-centered instructional style (Felder and Brent, 2016). Using a process of 1) identifying and defining the problem that must be solved, 2) defining criteria for the solution, and 3) identifying the disciplinary content areas that relate to the problem, students engage in a collaborative process of questioning, researching and ideating to design, build, evaluate and re-iterate until an acceptable solution is created. Instructional strategies used in the T/E DBL pedagogical approach are intentionally designed based on Gagne's events of instruction to promote students' knowledge construction in the procedural, declarative, schematic and strategic knowledge domains (Gagne, Wagner, Golas, & Keller, 2004, Wells, 2016c). The iterative design process requires students to reflect on their existing knowledge in all relevant subject areas in order to construct new knowledge and this is an important aspect of developing habits of mind (Jonassen, 1997). The predictive nature of designing a solution and testing the model or prototype in an iterative fashion presents opportunities (with instructional guidance) to refine one's understanding due to cognitive dissonance generated by observed inconsistencies (Festinger, 1962; Puntambekar & Kolodner, 2005). The central tenet of education is to increase students' understanding, and many researchers have argued that the T/E DBL approach is effective in increasing students' understanding through such cognitive dissonance (Cajas, 2001; Wells, 2010; Puntambekar & Kolodner, 2005; Barlex, 2003).

## ***2.2 Cognitive Science Underpinning I-STEM ED Pedagogical Approach***

A widely-used model of the process of learning is that human senses receive new input, which are held in a sensory register for a fraction of a second and passed on to working memory. In working memory, the information is processed and immediately stored in long-term memory or lost. When learners make strong emotional associations with the information or make sense of it through connections to some previously stored information, the new information is stored in long-term memory (Bransford, Brown & Cocking, 2000; Brown, Collins & Duguid, 1989). Without the associations or the sense-making the information is lost.

Although learners' construction of knowledge is linked to the activity, context, and culture in which it is learned, this construction of knowledge requires the individual to be engaged as the sole constructor of his/her knowledge, uniquely related to his/her previous knowledge (Brown, Collins & Duguid, 1989). Retrieval of stored information repeatedly strengthens the interconnectedness of stored information and its future recall at appropriate times is enhanced. In alignment with constructivist practices and with cognitive science research, the I-STEM ED pedagogical approach supports the development of cognitive connections required for integration and the transfer of knowledge and skills to novel situations (Huber & Hutchins, 2004; Brown & Kane, 1988; Perkins & Salomon, 1989).

From the perspective of a cognitive science, the cognitive demands naturally imposed through T/E design-based challenges require student use of the following four knowledge types:

- declarative knowledge, which includes definitions, concepts and principles of a subject,
- procedural knowledge, which is the practice used within the subject or discipline,
- schematic knowledge, which is the reasoning and relationship between concepts. and,
- strategic knowledge, which is knowing the appropriate utilization of concepts (NAGB, 2009; Shavelson, Ruiz-Primo & Wiley, 2005).

These hierarchical knowledge types reflect deeper learning when students are able to exhibit the interconnections between concepts and disciplines and demonstrate the use of the knowledge in developing a solution to the posed design challenge (Webb, 1997). However, isolated singular experiences of T/E DBL where students learn in this manner will not achieve the goal of developing the desired habits of mind and hand. Only repeated experiences in T/E DBL throughout their education would help students develop these habits.

Problem solving skills are not assessed in traditional science and mathematics standardized testing. When students are tested for their problem solving abilities in the traditional classroom the focus is on the extent of correctness of the end-result, and rarely, if ever, on the reasoning or procedures leading to the result (Docktor & Heller, 2009; Shavelson, Ruiz-Primo, Li & Ayala, 2003; Steif & Dantzler, 2005). Furthermore, the content

knowledge tested is directly related to what has been recently taught in the classroom, which does not require the solver's demonstration of metacognitive processes involved in critical thinking requiring selection of discipline specific content and practice knowledge.

In an integrative STEM education program, the T/E DBL approaches are consistently used "to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education" (Wells & Ernst, 2012/2015). Student assessments in such a program would also need to be designed to evaluate problem solving skills in addition to the more traditional standardized assessments.

### ***2.3 Characterizing problem-solving to develop assessment strategy***

Researchers agree that problem solving is a goal driven process that requires recognition of the nature of the problem, identification of the end-state that implies success, creation of a strategy to go from the current-state to the end-state, execution of the strategy and adaptation of changes in strategy based on difficulties encountered along the way (Reeff, 1999; Martinez, 1998; Hayes, 1989). When a problem is based in the real-world context with many unknowns, the recognition and understanding of the problem in a solver's perception is key to devising a process to solve the problem. This implies that no two real-world problems can be solved using the same knowledge or exact process (Reeff, 1999).

Two broad problem-solving categories have been characterized as: 1) well-structured, where all information needed to solve the problem are provided, and, 2) ill-structured, where there are many unknowns, many conflicting goals and multiple approaches possible for solving the problem (Jonassen, 1997). Well-structured problems are typical of problems practiced and assessed in the traditional science and mathematics classrooms. In contrast, ill-structured problems are more typical of real-world situations (known as authentic problems), and are more reflective of what professionals will encounter in the workplace. Solving such problems requires multiple disciplinary experts, often having multiple conflicting or vague goals, and where all the necessary information is not fully known. In the engineering educational setting, a design challenge, with or without model making, is closer to the ill-structured end of the spectrum of problems (Heywood, 2005). It is important to know the process involved in solving such problems in order to develop an effective assessment of students' PS skills.

For solving authentic problems, methods can be algorithmic or heuristic or a combination of both (Martinez, 1998; Jonassen, 2000; Ormrod, 2012). Algorithmic methods are typical of mathematical problem solving in the context of a classroom, where students learn step-by-step procedures on how to work out factoring for quadratic functions or long division. Heuristic methods are more like general strategies or rules involved in an engineering design-based iterative problem that can only be solved through execution and testing. While algorithmic methods are not useful in authentic problem solving, general heuristics alone are also not reliable in authentic problem solving without deep understanding of the content areas within which a problem is embedded (Perkins & Solomon, 1989). In an authentic problem situated within the context of science and mathematics instruction requiring the design of a solution, the method may be heuristic in creating general strategies for solving the problem, but algorithmic when it comes to utilizing specific mathematics and science knowledge to solve the problem. In addition, frequently practiced and accessed pathways to stored content in long-term memory help with recognition of content areas relevant to the problem, and to think and reason forward in order to evaluate the results of any particular action to help with progressing logically towards a solution (Perkins & Solomon, 1989).

Cognitive science reveals that the mental processes involved in problem-solving are based on knowledge and prior experiences of the solver (Ormrod, 2012; Newell and Simon, 1972). Prior knowledge is stored in long term memory and information gleaned from the problem are stored in short term or working memory. The latter has limited capacity and therefore can become overloaded during problem solving. This cognitive overload can hinder the solver's ability to successfully complete the solution. Therefore, the science, mathematics and engineering methods of problem solving recommend identifying and writing down (symbolically and visually) identified information (Heywood, 2005; Jonassen, 1997; Jonassen, Stroebell and Lee, 2006; Chi, Feltovich, and Glaser, 1981). This relates to the first phase of solving an engineering design-based problem: identification of the problem parameters, such as useful information given and unknowns. Metacognition is involved in mental

activities such as identifying and selecting appropriate conceptual knowledge, planning a strategy to use the conceptual knowledge, monitoring one's progress towards a goal (Jonassen, 1997; Chi, Feltovich, and Glaser, 1981; White and Fredrickson, 1998). When an authentic problem is encountered in a situation outside the classroom where the content was learned, it demands the solver's ability to recognize the discipline or topic and the specific content and practices relevant to the problem. Repeated experiences in solving such problems create the strong interconnected organization of information within a solver's long term memory and practiced habits of mind. In a traditional classroom assessment, problems encountered are often related to the content recently learned and the course or subject matter is the clue to recognizing the discipline and topic. This approach limits the transferability of the learning and knowledge gained to novel situations.

Prior research on development of problem solving skills indicates there are specific skills associated with solving authentic, ill-structured T/E design problems: 1) recognizing and identifying the problem, 2) recalling and organizing specific subject content relevant to the problem, 3) carrying out the procedural steps that are common practices within the subject, 4) looking back to see if the progression is logical, and, 5) stating the solution to the identified problem (Newell and Simon, 1972; Polya, 1973; Perkins & Salomon, 1989; Heller & Reif, 1984; Reeff, 1999).

### **3. METHODOLOGY**

#### ***3.1 Assessment of Problem Solving Skills***

For the problem solving activity in this study, a design-no-make T/E challenge was chosen. This approach was selected based on the Design-no-make (DNM) approach characterized in 1999 by David Barlex through the Young Foresight initiative (Barlex, 2003). At the time it was introduced, the aim was to help focus students' learning, and teachers' instruction towards the design phase instead of on the act of making the designed product. Research showed that this approach was valuable in helping students explore a wide range of design criteria, develop greater understanding of the technological concepts, and in promoting student enjoyment of the experience as well (Barlex & Trebell, 2008). From an instructional perspective, the distractions of making the prototype were removed from the learning experience, and thus gave students the opportunity to explore various ideas and concepts in greater depth (Barlex & Trebell, 2008). This type of a DNM challenge was equally suitable and instrumental in revealing students' use of schematic and strategic knowledge domains correlated to problem solving skills.

The T/E design-based challenge used in the research being reported was situated in the physics and mathematics content areas. Both physics and mathematics were components of the curriculum that is followed in the Governor's STEM Academy. Research indicates that a lack of literacy in these two content areas (physics and mathematics) contributes to challenges undergraduate students are faced with when entering postsecondary engineering programs (Budney, LeBold & Bjedov, 1998; Steif & Dantzler, 2005). One of the reasons first year undergraduate students do not continue in an engineering program is not having been inadequately prepared to apply the foundational knowledge in these subjects (ibid). Research into the nature and characterization of problem solving over several decades has identified a set of student abilities requisite of success for solving authentic problems outside the confines of a typical classroom (Newell & Simon, 1972; Polya, 1980; Perkins & Salomon, 1989; Martinez, 1998; Jonassen, Stroebell & Lee, 2006). Specifically, these student abilities are: 1) Useful description, both symbolic and descriptive, 2) Recognition and selection of relevant content applicable to the problem, 3) Use of the principles and practices of specific content identified to solve the problem, and 4) adherence to a devised logical strategy for solving the problem. This research study used parts of the previously discussed studies to develop, validate and utilize an assessment rubric to answer the research questions and sub-questions stated.

The DNMC selected for use in this research was aligned with the physics and mathematics state standards in the high school curriculum. The metacognitive question prompts were developed in order to elicit responses to demonstrate key student abilities (SAs) as identified in this study. A group of I-STEM ED experts were tasked with the alignment of the metacognitive prompts in the DNMC to an assessment rubric, as well as validating the levels within the rubric scores. The DNMC was administered to students in a traditional classroom with students having the same level of physics and mathematics as those in the I-STEM ED Governor's School program. Their responses to the DNMC were scored by the experts to conduct the reliability testing for the

rubric. The process resulted in a modified assessment rubric, as well as modification to several of the prompts used in the DNMC. This finalized DNMC was then administered to the sample of students from the graduating class of the Governor's School I-STEM ED program. Qualified STEM educators were trained as scorers (who were educators in STEM). Interrater reliability was established among these scorers using previously gathered student responses from the traditional classroom. Once reliability was established, scorers were asked to assess and score the responses from students participating in this research.

### 3.2 The DNMC and scoring rubric

The design-no-make challenge (DNMC) presented to the Governor's Academy high school students involved an authentic T/E design challenge encountered by engineering students at a major research university in the United States when addressing engineering problems confronting humanitarian workers in the country of Malawi (Fig. 1).

**Description of Scenario**

A small village in a third world country has determined that its most pressing need is for safe drinking water. A volunteer team determined the location of an appropriate underground spring and dug the well. The well is 10.0 meters deep and one way to access the water in the well, would be to lower buckets into the well. The concerns with using buckets to retrieve the water are, that the buckets will become dirty over time and defeat the purpose of the safe drinking water, and, using buckets would be time consuming, difficult, and create hardship for those who need the water. The volunteer team decided to use an electric submersible pump to bring the water safely and cleanly to the surface for storage and use.

**Challenge**

Your task in this challenge, is to design a suitably sized (power – measured in horsepower – hp) and priced (dollars) submersible pump to supply water at a rate of 35gal/min. Remember, in America we sell electric motors in horsepower, not watts, and 1.0 hp = 746 W. For pricing, use the information provided in the attachment.

Figure 1: The DNMC

The scoring rubric for DNMC responses was adapted from the rubric developed by Docktor (2009) to measure key student abilities (SAs) identified as indicators of their abilities to solve authentic problems outside the classroom context where the relevant subjects were initially learned. The dependent variables were overall student success (OSS) and the five key Student Abilities (SA1, SA2, SA3, SA4 and SA5). To obtain measures for each of the five SAs, student responses to the DNMC question prompts were scored using the adapted rubric, and thus providing numerical scores. The OSS was the sum of the student ability scores ( $OSS = SA1 + SA2 + SA3 + SA4 + SA5$ ). The following prompts were used to elicit responses matching each of the key student abilities to be measured.

- Q 1a) What is your understanding of the challenge described above? Describe using your own words, in a few sentences.
- Q 1b) Based on what you wrote above, draw a sketch to describe the scenario, and label the sketch to show the information provided above (e. g. the depth of the well is 10 meters). Use variables for what you do not know.
- Q 2) How could you determine the power of the water pump? State any laws and equations you would use and explain your strategy in a few sentences.
- Q 3) Based on your response to question 2 go through the process you have outlined, and show your calculations to determine the power of the pump (in horsepower).
- Q 4) Based on your work in question 3, what is the power of the motor you need? Using the motor pricing information provided, which motor would you pick and how much will it cost?



## 4. RESULTS

Numerical scores on the scoring rubric were aligned with each of the five student abilities as outlined in Table 1. Data collected from the scored DNMC question prompts were examined using descriptive statistics, the one-sample t-test for testing the significance of the overall success score (OSS, the sum of scores of the five SA), the covariance between each of the SAs and the OSS, and the strength of the correlation using an adjusted correlation coefficient. Although the sample size was small, based on the assumption that the sample-distribution is a good approximation of the population-distribution, bootstrapping techniques could be used to create a large number of repeated samples with replacement before calculating the statistic for the research samples (Efron, 1994, Cuming, 2014).

Table 1: Scoring Rubric – Key Student Abilities

SA1 USEFUL DESCRIPTION (Specific to a given problem)	5 The description provides appropriate details, and is complete.	4 The description provides appropriate details but contains 1 omission or error.	3 The description provides appropriate details but contains 2 omissions or errors.	2 The description provides details but contains 3 omissions or errors.	1 There is a description contains more than 3 omissions or errors, or is incorrect.	0 The response does not include a description.
SA2 SKETCH (Contains dimensioning, legible and correct units of measurement, labels for specific features or known items.)	The sketch provides appropriate details and is complete.	The sketch provides details but contains 1 omission or error.	The sketch provides details but contains 2 omissions or errors.	The sketch provides details but contains 3 omissions or errors.	There is a sketch but contains more than 3 omissions or errors or is incorrect.	The response does not include a sketch.
SA3 SPECIFIC APPLICATION OF PHYSICS	The specific application of physics is appropriate and complete.	The specific application of physics 1 omission or error.	The specific application of physics contains 2 omissions or errors.	The specific application of physics contains 3 omissions or errors.	The specific application of physics is inappropriate or has more than 3 omissions or errors, or is incorrect.	The specific application of physics is missing.
SA4 APPLICATION OF MATHEMATICS	The mathematical procedures are appropriate for solving this problem and complete.	The mathematical procedures are appropriate for solving this problem with 1 omission or error.	The mathematical procedures are appropriate for solving this problem with a 2 omissions or errors.	The mathematical procedures are appropriate for solving this problem with 3 omissions or errors.	The mathematical procedures are inappropriate for solving this problem or has more than 3 omissions or errors, or is incorrect	The mathematical procedures are entirely missing.
SA5 LOGICAL PROGRESSION	The problem solution is clear, focused, logically connected and complete.	The solution is clear and focused with 1 logical inconsistency and complete.	Parts of the solution are unclear, unfocused, and has 2 logical inconsistencies.	Most of the solution parts are unclear, unfocused, and 3 logical inconsistencies.	The problem solution is unclear, unfocused, and inconsistent.	There is no evidence of logical progression.

The primary conclusion drawn is that students immersed in an integrative STEM education program will perform significantly better (as assessed using their overall success score) in designing a solution to the design-no-make-challenge (DNMC) when compared with the performance of students in a traditional classroom (shown in Table 1). Results from the two-tailed one-sample t-test (Table 2), indicate that the mean OSS was statistically significantly higher by 4.455 (95% CI, 1.78 to 7.13) than the assumed mean performance score of 12,  $t(10) = 3.708$ ,  $p = .004$ . The hypothesized mean was generated from the pilot study conducted in a traditional classroom (one not within the Academy), where those students were completing the same physics course (using the same curriculum) as students in the Academy. The calculated effect size (Cohen's  $d$ ) of 0.8 indicated a large effect, implying that the strength of significance of the t-test is large enough to be practically significant.

Table 2: Results from the Two-tailed One Sample t-test for OSS

Test Value (hypothesized mean) = 12 (Bootstrap = 1000 samples)						
	<i>t</i>	<i>df</i>	<i>Sig. (2- tailed)</i>	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Overall Success Score	3.708	10	.004	4.455	1.78	7.13

A secondary conclusion drawn from this study is that four of the five specific student abilities identified and used in this research study strongly correlate to students' performance in authentic T/E design-based problem solving challenges (Table 3).

Table 3: Pearson's Correlations and Calculated Coefficient of Determination for the SAs

Student Abilities	PPM Correlation ( <i>r</i> )	Coefficient of Determination ( <i>r</i> <sup>2</sup> )
Useful Description	0.121 ( <i>p</i> > .05)*	0.015 (1.5%)
Sketch	0.635 ( <i>p</i> < .05)**	0.403 (40.3%)
Specific Application of Physics	0.916 ( <i>p</i> < .01)***	0.839 (83.9%)
Application of Mathematics	0.953 ( <i>p</i> < .01)***	0.908 (90.8%)
Logical Progression	0.918 ( <i>p</i> < .01)***	0.843 (84.3%)

\*Correlation is not statistically significant at the .05 level

Note: \*\*Significance at *p* < .05; \*\*\*Significance at *p* < .01

## 5. DISCUSSION

This study generated preliminary findings related to the benefits of the T/E DBL pedagogical approach within an integrative STEM education program where technology, engineering, mathematics and science courses are integrated and progressively sequenced within the four year Governor's STEM Academy curriculum. The sum of the individual scores for the five components representing five key student abilities (SAs) identified as the essential aspects of problem solving and critical thinking resulted in the OSS. From the data presented in Table 2, students achieved an average score of 16.45 points (out of 25 possible points). The t-test results showed statistical significance to the higher mean overall performance score of students in the I-STEM ED program (higher mean by 4.455; 95% CI, 1.78 to 7.13) when compared with the mean of 12 as obtained from the students in a traditional classroom.

The results from this study also indicate that when designing a solution to the DNMC, students' abilities to recognize, recall, select and utilize science and mathematics content and practices are significant to successful T/E design-based problem solving (outside the confines of the classroom where the science or mathematics was learned) as implemented in this study using a DNMC (Table 3). The coefficient of determination represents the percent of the data points that are closest to the line of best fit in the model, and is a measure of how well the regression line represents the data. A higher coefficient is an indicator of a better goodness of fit and can provide a good indication of prediction of the variations of one variable with respect to the other in the regression model. The abilities associated with the specific application of science, mathematics and the ability to logically progress towards the solution are better predictors of successful problem-solving. Specific instructional strategies leading to students better prepared for tackling authentic problems through T/E design-based learning will need to be further explored. As well, further research on student learning, specifically qualitative methods investigating how they select and utilize scientific and mathematical principles in solving T/E design-based problems, would provide additional insights into student learning and transfer of their learning. Furthermore, additional refinement of the modified rubric used in this study would be necessary to ensure its usefulness in science and technology education.

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# On Intelligence in Technology Education: Towards Redefining Technological Capability

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The Technology subject in general post-primary education is unique based on its conception and treatment of knowledge. The task specific utility of knowledge is emphasised and at the same time, in reflection of the breadth of technology in society, the variance in the context of learning tasks can be quite large. The subject is considered to have a fluid epistemology which directly affects how capability is contextually defined. The concept of technological capability has been ascribed multiple definitions however the more commonly aligned with model suggests it refers to a synthesis of knowledge, skills, values and problem solving in a technological context. However the combination of knowledge, skills, values and problem solving neglects to acknowledge intelligence in the form of domain general abilities which have been observed to have a significant effect on student performance. Therefore this paper argues for the integration of contextually relevant domain general abilities with current conceptions of technological capability.

*Key Words: Learning, Knowledge, Intelligence, Capability.*

## 1. INTRODUCTION

A laudable goal of technology education is its aspiration to develop technological capability in students (Davies & Rogers, 2000; Kimbell, 1994; Liou, 2015; Norman, 1998; Rauscher, 2011; Shaw, 2002; Tairab, 2001). However, there is an inherent difficulty in achieving this aim due to the ambiguity in what it means to be technologically capable (Black & Harrison, 1985; Gagel, 2004; Gibson, 2008). This is clearly evidenced through work examining constructs and qualities of capability in technology education (Cauty, Seery, & Phelan, 2012; Kimbell, 2009; Kimbell, Stables, Wheeler, Wosniak, & Kelly, 1991). This is not to say that the subject does not make a unique and meaningful contribution to general education, but it does create the potential for a lack of consistency in the provision of the subject (Atkinson, 2017). The often subscribed to model of technological capability offered by Gibson (2008) suggests that it refers to a synthesis of knowledge, skills, values and problem solving in a technological context. But there is a lack of utility in this model as it does not qualify an explicit epistemological boundary for the included components. However, such specificity may not be appropriate as will be discussed later. The inevitable result of the agenda to espouse technological capability is a relatively large degree of variance in the provision of the Technology subject (Atkinson, 2017). This variance results in uncertainty concerning practice. This is not necessarily negative as, for example, it arguably elevates Technology teachers' professional status by providing them with the autonomy to make decisions about the usefulness of knowledge for their students. However, this uncertainty does create a scenario whereby students may receive varying standards of technology education. Furthermore, qualifying the effect that engaging with technology education has on students generally is impossible, as even if the effect is determined for one cohort, another is not guaranteed to be guided under the same interpretation of a

technologically capable person. This paper argues that what is described as technological capability in existing models offers a definition which is too narrow. In accordance with this, it is argued that the construct of human intelligence should be integrated with existing definitions of technological capability to provide a more comprehensive description of capability which, despite its increased scope, offers more precision and hence, utility.

## **2. SITUATING THE ARGUMENT**

The concepts of learning, knowledge, intelligence and capability are central to this paper. They are all distinct but interconnected. However, they can be interpreted in several ways and explored through the lens of multiple paradigms. Therefore, before proceeding to contextualise each concept within technology education, the position taken regarding each of these needs qualification.

Becoming more capable in any context requires learning. Learning cannot be explained independent of memory systems and there are two core components in the human memory system; the working memory and the long-term memory. The working memory is associated with actively maintaining attention on information (Engle, 2018), or in other words, consciously thinking about something(s). The long-term memory describes stores of accumulated knowledge (Kirschner, Sweller, Kirschner, & Zambrano R., 2018) which can be recalled. Learning is defined as “a change in long-term memory” (Kirschner, Sweller, & Clark, 2006, p.75). As the long-term memory describes stores of knowledge, learning therefore “involves the acquisition of knowledge” (Mayer, 2002, p.226).

Since learning is associated with acquiring knowledge, what is meant by knowledge needs further clarification. Many taxonomies describing the nature of knowledge types exist (Alavi & Leidner, 2001; de Jong & Ferguson-Hessler, 1996; Huang & Yang, 2009). Gorman (2002) provides a taxonomy of four knowledge types which reflect those commonly found in other taxonomies. It is particularly useful for technology education as the knowledge types are associated with technology transfer. These knowledge types include declarative knowledge (knowing what), procedural knowledge (knowing how), judgment (knowing when), and wisdom (knowing why). Furthermore, there is a division between explicit knowledge and tacit knowledge (Collins, 2010; Polanyi, 1969) which is overarching and applies to each of Gorman's (2002) types of knowledge. Tacit knowledge describes that which cannot be explicated and explicit knowledge refers to that which can. This distinction reflects the nature of a piece of knowledge itself rather than the communication capacity of a person to explicate the knowledge. Therefore, the term knowledge is considered holistically to describe the multiple types of knowledge inclusive of both their explicit and tacit elements.

Like knowledge, the concept of intelligence can be defined in many ways and consists of multiple elements. One definition of intelligence relates to accumulated knowledge whereby a person's level of intelligence is considered as a product of what they know (Ackerman, 1996). However intelligence as a concept is much broader. The most comprehensive framework of intelligence, the Cattell-Horn-Carroll (CHC) theory (Schneider & McGrew, 2012), describes intelligence as consisting of a number of cognitive factors, arranged hierarchically into three strata. The first layer contains narrow or specific first-order factors. The second layer contains broad second-order factors whereby each second-order factor describes a group of related first-order factors. Finally, the third layer contains one third-order factor, general cognitive ability or general intelligence, which describes the commonality or positive manifold which emerges from the combination of second-order factors. The CHC theory does include factors associated with acquired knowledge, but it also includes sensory abilities, motor abilities, and domain general abilities associated with reasoning, speed and memory. The most important characteristic of CHC theory for this argument is this separation between acquired knowledge and domain general abilities.

## **3. CAPABILITY AS THE INTERACTION BETWEEN INTELLIGENCE AND KNOWLEDGE**

To define technological capability, it is first necessary to clearly establish what it means to be capable and as such, how to see evidence of capability. In any context, capability is observable through action. In the context of technology education this action refers to performance, both in terms of the process and product, in a task or problem. Hambrick et al. (2012) conducted a study examining performance in a geological bedrock mapping

task examining performance relative to between visuospatial ability, a domain general ability, and pertinent knowledge. They found that both visuospatial ability and knowledge could predict performance, but an interaction between visuospatial ability and knowledge predicted performance above and beyond the effects of the two variables individually. This suggests that capability can be described as the relationship between domain general abilities and knowledge. This result is supported by similar findings in Chemistry (Stieff, 2007) and in Physics (Kozhevnikov & Thornton, 2006). Based on this, capability in a given context can be described as the relationship between contextually relevant domain general abilities and contextually relevant knowledge. For technological capability, current definitions (Black & Harrison, 1985; Gibson, 2008) do not take contextually relevant domain general abilities into account.

#### **4. TECHNOLOGICAL CAPABILITY CURRENTLY DESCRIBES KNOWLEDGE**

Before discussing the introduction of domain general abilities into a definition of technological capability, the current conception needs to be examined to identify how they should be positioned. Gibson's (2008) model, as the most widely adopted model (e.g. Gibson, 2013; Sahin & Ekli, 2013; Seery, Canty, & Phelan, 2012), serves as an example in this case. Gibson's (2008) model is widely acknowledged to describe technological knowledge (Pool, Reitsma, & Mentz, 2013; Rauscher, 2011; Underwood & Stiller, 2014). Buckley, Seery, Power, & Phelan (2018) note why the components of Gibson's (2008) model describe knowledge by aligning them with the types of knowledge put forward by Gorman (2002). They argue that what Gibson (2008) describes as knowledge is synonymous with declarative or conceptual knowledge and that skills correspond with procedural knowledge. Buckley et al. (2018) note how Gibson (2008) conflates values with ethics, further arguing that being ethical aligns with capability while holding values does not, and that ethics has similarities with wisdom as both involve knowledge of why something should or should not be done. Finally, Buckley et al. (2018) argue that problem solving describes an action making it categorically different to knowledge, skills and values, as these are constructs which a person can have. Due to the temporal dimension of problem solving, it is similar to judgment, or knowing when to do something. However, if problem solving is considered as meaning the ability to solve problems, this is either disciplinary in which case requires wisdom, declarative and procedural knowledge to denote capability, or is domain general, in which case it is better considered as biologically primary knowledge (Geary, 2007, 2008) and not as being associated with capability.

If the current depiction of technological capability describes knowledge, or more accurately technological knowledge, the remit of this must be established. De Vries (2016) suggests that technological knowledge can be considered as being similar to applied scientific knowledge. He also characterises technological knowledge relative to its normativity, collective acceptance, non-propositionality and context-specificity. These defining characteristics make it impossible to explicate a strict epistemological boundary for technological knowledge. Furthermore, McCormick (1997) suggests that explicit technological knowledge will be relative to specific tasks and circumstances and Kimbell (2011) argues that technological knowledge is inherently different to scientific knowledge whereby scientific knowledge is concerned with literal truths and technological knowledge is more aptly associated with usefulness. Kimbell (2011) advocates for knowledge to be viewed as provisional in technology education, noting that learners reside in an "indeterminate zone of activity where hunch, half-knowledge and intuition are essential ingredients" (p.7). Finally, Williams (2009, pp. 248-249) argues that "the domain of knowledge as a separate entity is irrelevant; the relevance of knowledge is determined by its application to the technological issue at hand. So the skill does not lie in the recall and application of knowledge, but in the decisions about, and sourcing of, what knowledge is relevant".

#### **5. INTELLIGENCE RESEARCH IN TECHNOLOGY EDUCATION**

Considering capability as the interaction between domain general intellectual abilities and knowledge, it is clear that the concept of technological capability as it currently stands is missing an intelligence related dimension. The inclusion of domain general abilities, or general intelligence, is important as it is positively associated with a number of different constructs such as creativity, leadership, conscientiousness, happiness, mental health and longevity (Ritchie, 2015). From an educational perspective, it is positively associated with educational outcomes (O'Connell, 2018; Smith-woolley et al., 2018) with 50 years of research illustrating that it accounts for approximately 80% of the variance in student performance (Detterman, 2016; Wiliam, 2010). The concept of intelligence is especially important for technology education when considering the nature of learning with

respect to technological knowledge. Based on how technological knowledge is described (de Vries, 2016; Kimbell, 2011; McCormick, 1997; Williams, 2009), the transferability of knowledge between tasks is likely to be less than in other subjects. For example, in one problem students may be designing a form of technology for a specific person, such as a prosthetic limb for an adult, and in the next they may be designing for general use such as a toy for children. This means that the accumulation of knowledge in technology education that is pertinent and transferable between tasks can be relatively uncertain. Another finding from Hambrick et al.'s (2012) study was that the importance of domain general abilities in predicting performance was higher when pertinent knowledge was lower. Due to the varying contexts of problems in technology, there is less likelihood of students having high levels of associated knowledge when posed with a learning activity relative to other subjects. As such, general intelligence or domain general abilities are likely to have significant effects on performance in technology education, meaning the magnitude of influence these abilities have on capability in the subject is likely to be high and they should therefore be considered in models of technological capability.

## **6. TOWARDS A NEW DEFINITION OF TECHNOLOGICAL CAPABILITY**

The concept of intelligence is broad. The CHC theory (Schneider & McGrew, 2012) describes 84 specific first-order factors and the integration of all of these factors would likely hinder the development of technological capability more than assist it. However, as discussed the theory contains factors associated with acquired knowledge, sensory abilities, motor abilities and domain general abilities. Currently, technological capability describes knowledge, and sensory and motor abilities are important in technology education but only to the extent of enabling students to engage in the cognitive activity of modelling or the physical activity of making. Integrating intelligence into the meaning of technological capability essentially means integrating the contextually necessary domain general abilities. Buckley, Seery, Canty, & Gumaelius (2018) hypothesised that one second-order factor of intelligence, fluid intelligence, which describes “the use of deliberate mental operations to solve novel problems” (Primi, Ferrão, & Almeida, 2010, p.446) aligned appropriately with technology education due to the prevailing conceptions of technological knowledge. By examining 16 domain general first-order factors relative to fluid intelligence, they observed that a combination of visualization, inductive reasoning and memory span could statistically account for between 28% and 43% of the variance in technology education students fluid intelligence. They also argue that the importance of these factors is theoretically sound as memory span affords the capacity to retrieve and hold chunks of information in the working memory while engaging with a problem or task, visualization builds on this capacity by allowing for information to be generated, represented and manipulated and inductive reasoning (I) allows for inferences to be made based on the available information. By allowing for information to be retrieved, stored, generated, represented, manipulated and inferred, these factors, both empirically and theoretically, can account for all of the necessary mental operations presented in established problem solving frameworks (M. Carlson & Bloom, 2005; Gigerenzer, 2001; Gigerenzer & Todd, 1999; Novick & Bassok, 2005; Schraw, Dunkle, & Bendixen, 1995; Wang & Chiew, 2010). Therefore, while there are many factors of intelligence, it is argued that integrating fluid intelligence with a focus on visualization, inductive reasoning and memory span, with the conception of technological knowledge would better describe what enables and constitutes as technological capability. Finally it is important to consider how these factors can be integrated in the context of technology education. While this research is still emerging, preliminary results show that visualization does relate to educational performance in technology education but has a complex relationship with external modelling (Buckley, Seery, & Canty, 2018) and importantly that it can be developed through targeted interventions (Sorby, 1999, 2009; Stieff & Uttal, 2015; Uttal et al., 2013). Furthermore, inductive reasoning has also been shown to be malleable and can be developed through interventions (Klauer & Phye, 2008) but it has not been considered relative to technology education. Research concerning memory span indicates that it is fixed (Cowan, 2001; Miller, 1956) and cannot be meaningfully impacted through interventions (Harrison et al., 2013; Redick et al., 2013; Thompson et al., 2013). Similarly research concerning fluid intelligence also suggests that interventions other than engaging with general education do not have a meaningful effect on its development (Au et al., 2015; Ritchie, 2015). However while they may not be able to be developed through interventions, this does not restrict their consideration in terms of practice and pedagogical approaches can be underpinned by cognitive frameworks.



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# Investigating the Relationships between Spatial Ability, Interest, and Task Experience on Knowledge Retention in Engineering Education

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Spatial ability has been established as having a significant effect on performance and subsequently on retention in engineering education. However, the cause for this phenomenon is not yet fully understood. Based on previous findings, it is posited that spatial ability has an effect on the students' capacity to acquire knowledge. This study aspired to investigate this from the perspective of knowledge retention in an authentic engineering education environment. A cohort of first year undergraduate engineering students ( $n = 83$ ) voluntarily participated in this study. Three psychometric tests of spatial ability were administered to the cohort. After eight weeks, this was followed by an experimentally designed lecture on novel foundational engineering content and an associated retention test with perceived task experience and interest measured through 9-point Likert-type items. Results suggest that interest and spatial ability have an effect on knowledge retention, however no effect was observed between retention and task experience other than of perceived difficulty. A discussion is presented describing the implications of this study for future research.

*Key Words: Engineering education, spatial ability, learning, retention.*

## 1. INTRODUCTION

While many definitions have been ascribed to spatial ability (Buckley, Seery, & Canty, 2018), Lohman's (1996, p.126) description of it as “the ability to generate, retain, and manipulate abstract visual images” is regularly cited within the pertinent literature (Colom, Contreras, Botella, & Santacreu, 2001). Spatial ability is often investigated in attempts to gain insight into the variables which affect student performance in engineering education. There are many notable findings which have emerged through this research. For example, spatial ability has been observed to correlate with student performance (Alias, Black, & Gray, 2002; Sorby, 2009) and to be malleable and susceptible to change through targeted interventions (Stieff & Uttal, 2015; Uttal et al., 2013). Specifically in relation to undergraduate engineering students, Min, Zhang, Long, Anderson, & Ohland (2011) in a study of more than 100,000 students found a dropout or “failure” rate of 21.9% and that this is most likely to occur in the third semester of study. In light of this, the importance of spatial ability for engineering education is exemplified through the work of Sorby, who showed both that spatial ability can be developed in engineering students, and that subsequent to spatial training, students demonstrated statistically significant performance gains and improved retention (Sorby, 1999, 2009; Sorby, Casey, Veurink, & Dulaney, 2013). However, despite the work highlighting that spatial ability is important, there is uncertainty as to why this cognitive ability has such profound implications (Ramey & Uttal, 2017). Considering the finding that the dropout rate of undergraduate engineering students is highest in the third semester (Min et al., 2011), Uttal and

Cohen (2012, p.168) speculate that “spatial skills may be a gatekeeper or barrier for success early on in STEM majors, when (a) classes are particularly challenging, and (b) students do not yet have the necessary content knowledge that will allow them to circumvent the limits that spatial ability imposes. Early on, some students may face a Catch-22: they do not yet have the knowledge that would allow them to succeed despite relatively low spatial skills, and they can’t get that knowledge without getting through the early classes where students must rely on their spatial abilities”.

## **2. STUDY FOCUS**

It is posited that the higher student dropout rate in engineering education in the third semester occurs in students who have not developed the necessary basic knowledge to support the advanced learning required in subsequent years. Considering that spatial ability has been found to support engineering education performance and retention, it is further posited that a higher level of spatial ability supports knowledge acquisition when there is a low degree of knowledge available to learners to build upon. Mayer (2002) describes learning as involving the acquisition of knowledge and subsequently Kirschner, Sweller and Clark (2006, p.75) defined learning as “a change in long-term memory”. The long-term memory describes stores of knowledge organised into schema with Piaget (1970) describing this organisation process as cognitive adaptation. This process requires knowledge to be processed in the working memory and subsequently encoded into the long-term memory (Terrell, 2006). The working memory has capacity limitations (Cowan, 2001; Miller, 1956) and temporal limitations (Peterson & Peterson, 1959) and these limitations cause the induction of cognitive load when processing information (Sweller, Ayres, & Kalyuga, 2011) which reduces the potential for learning. From a pedagogical perspective, when information is presented to learners, in order for information to be processed in the working memory it is necessary for students to be able to retain the information. Ruiter, Loyens and Paas (2017) investigated the effect of cycling on a desk bike on students’ ability to retain information presented during a lecture. During their study, they investigated knowledge retention relative to task experience and affective state. The task experience variables included self-reported attention, effort required to focus, effort required to understand the lecture content, lecture difficulty, enjoyment and post-lecture question difficulty. Participants were also asked about their interest in the lecture content. Building on the work of Ruiter et al. (2017), this paper aims to explore why spatial ability may impact knowledge acquisition. Specifically, the effect spatial ability has on the capacity to retain knowledge is investigated in conjunction with task experience and content interest in an experimental study.

## **3. METHOD**

### ***3.1. Approach***

The study aimed to investigate the potential effect that spatial ability has on engineering students’ capacity to retain recently presented information. Additionally, based on the work of Ruiter et al. (2017), task experience was also examined to explore the potential effect it has on the relationship between spatial ability and retention. Due to the importance of spatial ability in the early years of undergraduate engineering education (Min et al., 2011; Sorby, 2009; Uttal & Cohen, 2012), a cohort of first year engineering students were invited to volunteer as participants. Initially, participants completed three well-established psychometric tests of spatial ability. Subsequent to this, an experimental lecture and associated retention test were designed and administered to participants. Perceived task experience of these activities was also captured.

### ***3.2. Participants***

The study cohort comprised of 122 first year Engineering undergraduate students enrolled in a common entry engineering course or an aeronautical engineering course. Of the 122 students who volunteered to engage, only 83 completed each part of the study and are reported on in this paper. Participants were invited to voluntarily engage with this study as part of their common engagement with an introductory module focussing on engineering design and manufacturing. The cohort ( $n = 83$ ) consisted of 69 males and 14 females and had a minimum age of 17 and a maximum age of 26 ( $M_{\text{age}} = 18.19$ ,  $SD_{\text{age}} = 1.18$ ).

### 3.3. Instruments

Three psychometric tests of spatial ability were administered in this study. The Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) (Bodner & Guay, 1997; Guay, 1977) test was used as it has been shown to be psychometrically sound specifically with engineering students (Maeda, Yoon, Kim-Kang, & Imbrie, 2013). This was complimented with the Paper Folding Test (PFT) and the Surface Development Test (SDT) from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976). The three tests were used as they each require a different cognitive action (i.e. mental rotations, mental folding, and surface development) and therefore through their combination, task related bias is reduced.

The duration of the experimental lecture was 25 minutes. The content was new for all participants when considered as part of their formal undergraduate education. The lecture focused on the joining of materials, specifically permanent and non-permanent methods of mechanical joining. A PowerPoint slideshow guided the delivery of the lecture. Prior to the beginning of the lecture, participants were informed that there would be a retention test directly after it.

The retention test contained nine multiple part recall questions with a total of 28 declarative answers required. Questions specifically related to the content of the lecture. The answers for each question were presented visually on the slideshow and aurally by the lecturer. An example of a question with multiple answers required is; “mechanical joining has two main sub groups: list them below”. All answers were scored as either correct if entirely accurate (1 point) or incorrect (0 points). Students were given 20 minutes to complete the test.

Task experience was explored based on the variables examined by Ruiter et al. (2017) which included self-reported attention, effort required to focus, effort required to understand the lecture content, lecture difficulty, enjoyment and post-lecture question difficulty. Interest in the lecture content was also examined. Each of these variables was captured through a 9-point Likert-type question based on the Paas (1992) Cognitive Load Rating Scale. For example, for self-reported attention participants were asked to “rate the level of attention you paid during the lecture” on a 9-point Likert-type scale from “very, very low attention” to “very, very high attention”.

### 3.4. Implementation

The first stage of implementation involved the administration of the three psychometric tests of spatial ability. Participants engaged with this in six groups (M = 20.33 per group). Each testing session lasted one hour in duration with 20 minutes afforded for the PSVT:R, 6 minutes afforded for the PFT and 12 minutes afforded for the SDT. Tests were administrated in a different order to each group to reduce the potential effect of order bias.

The experimental lecture and retention test were delivered 8 weeks after the administration of the psychometric tests. The lecture was delivered by the participants’ regular module lecturer. Immediately following the lecture, participants answered the Likert-type questions related to the variables of interest, attention, effort required to focus, effort required to understand the lecture content, lecture difficulty, and enjoyment. This was immediately followed by the retention test which was administered by two researchers. Subsequent to the retention test, the final Likert-type item concerning post-lecture question difficulty was given.

## 4. RESULTS

Descriptive statistics for each of the variables examined in this study are presented in Table 1. Skewness and kurtosis values for all tests were within acceptable limits of between  $\pm 2$  (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006) (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006).

Table 1. Descriptive statistics.

	N	Min	Max	M	SD	Skewness	Kurtosis
PFT	83	4	20	14.080	3.104	-0.388	0.485
SDT	83	7	60	42.843	14.659	-0.676	-0.597
PSVT:R	83	7	29	21.422	4.819	-0.625	-0.264
Retention	83	3	21	11.900	3.900	0.048	-0.682

	N	Min	Max	M	SD	Skewness	Kurtosis
Interest	83	3	8	6.710	1.185	-1.136	1.033
Attention	83	4	9	6.660	1.129	-0.443	0.153
Effort focus	83	3	9	5.730	1.398	0.022	0.007
Effort understand	83	3	9	5.880	1.501	0.033	-0.679
Lecture difficulty	83	1	8	4.700	1.520	-0.112	-0.146
Enjoyment	83	3	9	6.050	1.396	-0.529	0.162
Question difficulty	83	3	9	6.270	1.170	0.072	0.256

The three psychometric tests of spatial ability all correlated positively with each other (average  $r = .492$ ,  $p < .000$ ). A factor analysis was conducted with the three psychometric tests as variables and the first factor accounted for a large proportion of the variance (66.15%) with factor loading ranging from .693 to .707. Therefore, following the approach used by Hambrick et al. (2012), a composite measure of spatial ability was created by averaging z-scores for each of the psychometric tests.

A correlation matrix is presented in Table 2. The Spearman's Rho statistic was used to account for the ordinal data collected through the Likert-type items. As the spatial ability variable and retention test represent scaled data, a Pearson's correlation was computed between these variables and a statistically significant correlation ( $r = .317$ ,  $p = .004$ ) was observed.

Table 2. Spearman's Rho correlation matrix.

		1	2	3	4	5	6	7	8
1. Spatial ability	$\rho$	–							
	$p$								
2. Retention	$\rho$	.206	–						
	$p$	.062							
3. Interest	$\rho$	.103	.368**	–					
	$p$	.356	.001						
4. Attention	$\rho$	-.106	.120	.467**	–				
	$p$	.341	.280	.000					
5. Effort focus	$\rho$	-.028	.051	.069	.028	–			
	$p$	.803	.647	.533	.801				
6. Effort understand	$\rho$	-.056	-.051	.178	.130	.650**	–		
	$p$	.613	.650	.107	.243	.000			
7. Lecture difficulty	$\rho$	-.187	-.216*	-.152	-.100	.058	.200	–	
	$p$	.091	.049	.169	.367	.600	.069		
8. Enjoyment	$\rho$	.135	.200	.505**	.315**	.136	.237*	-.040	–
	$p$	.225	.070	.000	.004	.220	.031	.719	
9. Question difficulty	$\rho$	.124	-.237*	-.130	.031	.017	.086	.406**	.040
	$p$	.266	.031	.242	.783	.879	.442	.000	.723

Note. \*\*. Correlation is significant at the 0.01 level (2-tailed). \*. Correlation is significant at the 0.05 level (2-tailed).

Based on the correlation analysis, retention was observed to have a statistically significant positive correlation with interest in the content ( $\rho = .368$ ,  $p = .001$ ) and statistically significant negative correlations with perceived lecture difficulty ( $\rho = -.216$ ,  $p = .049$ ) and question difficulty ( $\rho = -.237$ ,  $p = .031$ ). Furthermore, perceived enjoyment was observed to correlate positively with interest in the content ( $\rho = .505$ ,  $p < .000$ ), invested attention ( $\rho = .315$ ,  $p = .004$ ) and effort required to understand the content ( $\rho = .237$ ,  $p = .031$ ). Interest in the lecture content was also found to correlate with the perceived amount of attention invested in the lecture ( $\rho = .467$ ,  $p < .000$ ) and perceived lecture difficulty was found to correlate with how difficult the questions in the

retention test were perceived to be ( $\rho = .406, p < .000$ ). Finally, the strongest correlation was observed between the amount of mental effort required to understand the content and the amount of mental effort required to focus during the lecture ( $\rho = .650, p < .000$ ).

A final stepwise multiple regression analysis was conducted with the retention test as the dependant variable. The results of this (Table 3) suggest that a synthesis of interest in the content, spatial ability, and difficulty in the questions within a retention test statistically accounted for 25.3% of the variance in performance in the retention test.

Table 3. Stepwise multiple regression analysis with performance on the retention test as the dependant variable.

IV	Model 1			Model 2			Model 3		
	B	SE B	$\beta$	B	SE B	$\beta$	B	SE B	$\beta$
1	1.220	.340	.371**	1.101	.330	.335**	.1.013	.325	.308**
2				2.532	.932	.272**	2.702	.916	.291**
3							-.696	.328	-.209**
R <sup>2</sup>		.138			.210			.253	
$\Delta F$		12.915**			7.372**			4.510**	

Note: \*\*  $p < 0.1$ . Independent variables (IV): 1 = interest, 2 = spatial ability, 3 = question difficulty. Dependant variable = retention.

## 6. DISCUSSION

The study aspired to gain further insight into the role of spatial ability in learning in engineering education. Specifically, the study explored whether spatial ability had an effect on knowledge acquisition through having a relationship with students' capacity to retain recently presented information. The results of this study suggest that spatial ability does relate to knowledge retention, however the observed correlation was weak ( $r = .317, p = .004$ ).

Interestingly, when considered with the task experience variables examined by Ruiter et al. (2017), the results of the regression analysis (Table 3) indicate that a synthesis of interest in the content, spatial ability and the perceived difficulty of the test items was found to account for 25.3% of the variance in how much information was retained ( $F(3,79) = 8.916, p < .000$ ). However, as the test item difficulty is associated with the methodological tool rather than characteristics inherent to the participants, it is of interest to examine the relationship that a combination of interest in the content and spatial ability have with performance in the retention test. When just these two variables were considered in the regression analysis, a statically significant relationship was found ( $F(2,80) = 10.651, p < .000$ ) with interest in the content having more influence over performance in the retention test ( $\beta = .355$ ) than spatial ability ( $\beta = .272$ ). Therefore no task experience variables, with the exception of the perceived difficulty of the test items, were observed to influence the amount of information that was retained. So while this suggests that spatial ability has an effect on students' capacity to retain information, it does not provide insight into why this relationship exists. Furthermore, while not found to be a statistically significant predictor in the regression analysis, the statistically significant negative correlation observed between perceived lecture difficulty and retention ( $\rho = -.216, p = .049$ ) is also important to consider. Similar to the relationship between perceived item difficulty and retention performance, this provides insight for methodological considerations in future studies.

While not the agenda of the study to examine, a number of relationships between the task experience variables were observed, however many of these appear intuitive. For example, participants appeared to enjoy the lecture more if they were interested in the content and as such they invested more attention. Additionally, students who perceived the lecture to be more difficult also found the retention test questions to be more difficult. Finally, participants who had to invest more mental effort to understand the content also had to invest more effort in focussed in general during the lecture.



As this study was both experimental and exploratory, it would be inappropriate to deduce implications for engineering education practice at this stage. However, a number of implications for further research have emerged. In particular, a replication study is warranted to confirm the results as the lecture and retention test were both experimentally designed. In subsequent replications, it would be of particular interest to use different fundamental engineering content as the basis for the lecture and also for the lecture to be delivered by different people. Considering that there was no apparent influence on retention stemming from perceived task experience, this would also be of interest to confirm as if perceived task experience has no effect on the amount of information which could be retained by students this would have significant implications for practice.

One arguable limitation of this study was that the lecture was given to the participating cohort as a single group meaning there could have been distractions to some participants as a result of the actions of others. However, this was designed specifically to mirror authentic educational provisions so while it may have implicated the results of the retention test, such environmental characteristics are considered pertinent at this stage.

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# Supporting Learning Design Language in Primary Education

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Learning in Design and Technology (D&T) education has often a collaborative nature. Recently, it has been acknowledged that although collaboration and communication skills are learned through D&T education, it is necessary to support the development of these language skills. One of these skills is the ability to present design ideas to stakeholders outside the classroom. In our case study, pupils aged 9-12 years provided input for professional sport designers and presented their intermediate ideas to them half-way a six-week co-design project. Even when pupils are skilled communicators, it may be difficult for them to present design ideas. The language of design and creativity has specific features that most pupils are unaware of and have not yet experienced in an active way. To talk about a design that does not yet exist in the physical world, but is only a possibility, requires specific skills. As a result, the involved professional designers will quite often have difficulties in grasping the pupils design ideas and their feedback to forward the design idea may not achieve its full potential. Therefore, in our case study, genre-pedagogy was used as a reference to support building the design language field. The teacher taught pupils how to present ideas by using learning strategies, like modeling design presentations with a video, joint construction using worksheets and pupil-led construction of presentations on their own design. The results indicate that pupils discovered the importance of naming an design idea, using a problem-solution narrative structure and paying attention to the user, but they did not apply all these features in their own presentations. In the last session with the problem owner, the pupils were able to elaborate their design idea during the presentation with body language, adding drama, gestures and role-play.

*Key Words: Communication Skills, Co-design, Human Centred Design, Design Based Learning.*

## 1. INTRODUCTION

In Human Centered Design the role of the user has been amplified. Many different approaches exist to involve users in an early stage in the design project and take their wishes and experiences into account. Although observing and interviewing are useful, more recently users are asked to do user research among their peers (Klapwijk & Van Doorn, 2015) and to develop design ideas in cooperation with the professional designers jointly throughout various cycles (Maguire, 2001).

Co-design projects are also undertaken with children (Druin & Inkpen, 2001; Klapwijk & Van Doorn, 2015; Schut, van Doorn, Klapwijk, & Buchner, 2017; Van Mechelen, Gielen, vanden Abeele, Laenen, & Zaman, 2014), often in a school-context. As such children provide input for social change by sharing their experiences and design ideas with professional designers; however, attention for learning goals and skill development of the children during these projects has been limited up till now.

The project “Co-design with Kids” of the Delft University of Technology and partners is meant to make a change in this respect by simultaneously striving for educational goals and relevant input for professional designers.

Real life design challenges offer pupils the opportunity to use language in a functional way (Halliday & Hasan, 1989). However, in our first series of case-studies we observed that professional designers in co-design projects quite often do not get sufficient information from intermediate design presentations to understand the children's design ideas. The lack of proficiency in design language hampers co-design projects in various ways. First, the professional designer does not get high quality user-input. Second, the dialogue with the professional designers and their feedback to forward the design idea did not achieve its full potential.

Communication in design goes beyond the use of grammar and punctuation and seeks to find meaning in a functional way. The genre-pedagogy that started at the Sydney School (Rose & Martin, 2012, p. 321) is based on the understanding that language is goal orientated, i.e. it is important what the language "does for you", and that language is always related to a social context (Malinowski 1935; Wagner, 2015). Therefore, it benefits design-based education by guiding how pupils can use language in a functional way to present their design ideas.

Halliday (1976), who's language theory is incorporated into pedagogy, used the term **register** for particular language features that depend on the context of the situation. The register has three main concepts: the field (social activity of expressing ideas), tenor (roles taken when communicating ideas) and mode (channels of communication when sharing ideas). In this paper we focus on the field of design language. We analyze three specifications to present design ideas: The functional name (van Dijk & Hajer, 2018), problem-solution authentic scenario (Fox-Turnbull, 2018) and user feelings (Haven, 2007).

To foster the ability to develop the field of design language we use as reference the teaching learning curriculum-cycle suggested by Rothery (1995) It has 4 main stages:

1. Building the Field (getting to know the concept of a subject),
2. Deconstructing (teaching-led examples of a certain genre),
3. Joint construction (teacher and pupils collaborate to create a text using a genre),
4. Independent construction (learning evidence written by pupil using the genre taught previously).

This cycle has proven to be a powerful resource for supporting the literacy development (Christie & Derewianka, 2010; Gibbons, 2002; Humphrey, Macnaught, & Others, 2011; Knapp & Watkins, 2005; Rose & Martin, 2012). We use the genre-cycle as a strategy to focus on how students learn to present their design ideas.

In the design literature and in the practice of industrial design, we identified a number characteristics of design presentations. First of all, new design concepts are usually given a (working) title or name during the design process. Van Dijk (2018) explains that the artifact's name says something about the functional purpose of the artifact. Second, many design presentations follow a problem – solution structure. A problem or unmet desires in the current situation, is followed by a proposed solution(s). Third, unlike the language of science that highlights objectivity and frequently uses nominalizations (Christie 1998, Van Dijk 2012) and has an abstract nature (Van Dijk, Hajer, Scharren, de Vos 2013), designers use personal, subjective language (Eckert and Stacey 2000). Although designers may use descriptions and explanations – as the design is also grounded in science and research – a narrative approach is often at the foreground. This is clearly seen in storyboards that are visual representations of the design in its context of use over time (Van Boeijen e.a., 2013, p97) and in written scenarios (Van Boeijen e.a, 2013, p 99). Scenario's may contain a neutral sequence of steps but may also be written as a moving and epic narrative (Van Boeijen e.a, 2013, p 99). These elements of the genre of design presentations can be learned through the teaching learning curriculum cycle developed in the genre pedagogy.

Our main research question was: "How to support upper primary pupils in applying the specific genre of design language when presenting design ideas?" To answer this question, an educational design set-up was selected to understand the benefits of creating a learning environment to develop design language. A sports research group of The Hague University (HU) served as client and provided the design challenge. Their role in the learning process was to give the pupils a real problem within a context.

From session 4 to 6 we analyzed the language achievements in the pupil-led construction of their design presentation by answering the following questions:

- What was achieved in terms of supporting the pupil's ability to name a design idea?
- What was achieved in terms of supporting the pupil's ability to use the problem-solution authentic scenario?
- What was achieved in terms of supporting the pupil's ability to express the user's feelings?

## 2. METHOD

The set-up was developed in collaboration with a teacher at an International School in the Netherlands, and HU. The problem owner proposed to design the gym of the future as the design challenge for primary education pupils. The assignment was too broad and along with the PE teacher we decided to narrow it down to focus the challenge on three different types of users depending on what motivates them to move. The PE teacher specified three categories: leisure, competition, and fitness. These categories led pupils to create personas. They were asked to develop a sport activity for at least two different end users. The design was presented twice to the sports research group, halfway in session 4 and at the end of the project in session 6, to enable pupils to use the client's feedback in elaborating their design idea and to inform the client

The design project was implemented by the class teacher along with the PE teacher and at times supported by one of the authors of this article – in six sessions of two hours each. The class consisted of 20 pupils (aged 9 to 12) with different cultural backgrounds and various mother tongues. The project was conducted in English and although most pupils were fluent in English, a few number of pupils had a lower English level as they were new to the International school system. The six sessions followed the well known design-cycle, see figure 1.

In addition, we used the curriculum cycle from the genre-pedagogy and adapted it to our need to develop the field of design language (Figure 1). In the first two sessions the pupils conducted a teacher-led activity to characterize the genre-pedagogy applied in the case study and discuss the features of design language and how the end user of their design could prefer a certain reason to do sports like: leisure, competition or/and fitness. In session three, the teacher-led activity consisted of modeling by using a video from a Dutch television show "The best idea of Holland". Afterwards the teacher and pupils analyzed the video and deconstructed the features of design language in the presentation. Later on, they used a worksheet to start designing their sport activity. In appendix 1 we share the structure of the worksheet to support their design activity.

Afterwards, the pupils made a video of their first design for the problem owner. The problem owner sent feedback with an audio file. The teams were asked to answer a guiding framework that included the following questions:

What did you come up with?

What's the purpose?

Who is it meant for?

What makes it an original idea?

What do you think you could elaborate more on?

In session 4 the pupils listened to the audio and based on the feedback of the problem owner adapted their design. This help the students further to develop their design ideas.

Throughout the design project, the lessons were videotaped and pupil material was gathered and analyzed focusing on how children learn to present design ideas. The data was analyzed using the structure of the teaching learning curriculum-cycle and focused on three elements (naming, problem-solution structure and user feelings).

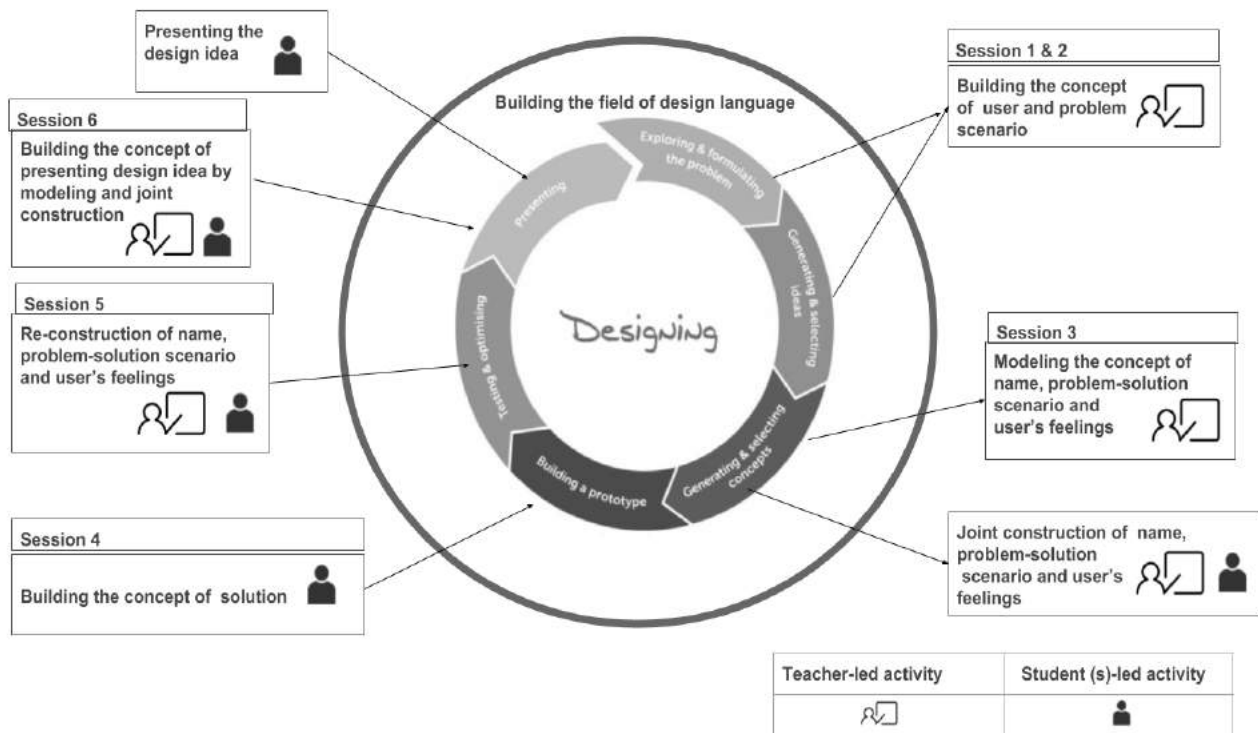


Figure 1. Building the field of design language

### 3. RESULTS AND DISCUSSION

The teacher used the curriculum cycle loosely to explain the features of design language. In the first two lessons of building the field of design language the learning objective was to harvest previous knowledge from pupils. For example, different reasons to move, different types of activities and gym facilities.

In session 3 the pupils watched a video that modeled a way to present a design idea. The video had different modes of communicating the problem-solution scenario. For example, the actress used gestures and role-play to express her feelings before and after using the design. After watching the video, the example was discussed with the whole class as illustrated in box 1.

**Box 1**

**Teacher:**

What was the challenge?

**Student 1:**

Why Nasa materials?

**Student 3:**

They are trying to convince people

That's not true (when at the advertisement they mentioned that they use materials from the NASA)

**Teacher:**

So what was the problem?

**Student 1:**

to make the it no so heavy.

The problem was that she was trying to carry something heavy

**Teacher:**

What did you notice then?

**Student 2:**

I noticed that they were talking about the NASA and materials from the NASA

**Teacher:**

Yeah, they did mention the NASA, why?

**Student 3:**

It did also say German quality, I don't know why?

**Teacher:**

Did they say that? Why did they say German?

**Student 3:**

Because want to say it's good quality.

**Teacher:**

What type of things come from Germany?

**Student:**

Cars, like Mercedes, BMW, Volkswagen

**Teacher:**

Generally speaking German things are good. One more.

**Student ?:**

Before she looked was sad and when she gets the thing she looked happier

**Teacher:**

Well spotted, there is a before and after, wasn't it?

Before she was all worried with this heavy thing and after she was happier with this German, NASA space bucket holder thing.

These led to a discussion in the class among the teacher and pupils where they were able to pinpoint the 3 key features of the design language.

In the next activity pupils used a worksheet enabling them to start elaborating their design idea. This highlights the joint construction to build the field of design language. We realized that it is fundamentally intertwined with the pupil-led construction of the final outcome. The tenor between teacher and pupils elaborating the design idea and refining the concepts as the main components was sometimes lead by teacher or pupil. The teacher questioned them in order to guide them towards a more refined elaboration of their design idea and presentation. The problem owner gave feedback that helped one of the teams to be more specific about their name, the pupils reacted positively to the feedback and build up on it to move on the next design phase.

### What was achieved in terms of supporting the pupil's ability to name a design idea?

Four of the five teams were able to link the function of the design to their name in the final presentations. For example: "Carry the king", "Obstacle Monkey", "Exercise Tag" and "Colony". The other team decided to make a combination of words from the two games they were inspired by to make their game, they called it "Scrumble". In table 1 we present the evolution of the name during the design process.

Table 1. Name of the game in the intermediate and final presentation

Team	Name intermediate presentation	Name final presentation
1	Dragon	Obstacle monkeys
2	No name mentioned	Colony
3	Carry the king	Carry the king
4	No name mentioned	Scrumble
5	No name mentioned	Exercise tag

In the presentations in session three only two teams mentioned a name for their game. Whereas the name "Carry the king" was functional in showing the nature of the game, this was not the case with the name "Dragon" by the other team. This is shown by the name itself but also by the reaction of the problem owner to this design team "Can you say something about the name of the game? Why is it called dragon game?". As a result, the team changed the name later on to "Obstacle monkey". In the final presentations, all teams used an attractive name related to a core element of the game.

## **What was achieved in terms of supporting the pupil's ability to use the problem-solution authentic scenario?**

During the final presentations four out of five teams describe a problem that is solved by the new game, for example.

“Well it's not the same (kind of game) as usual. It's by two, but usually you just go run for fun, here's it's like a bit competitive” (Team: Obstacle Monkey)

“The idea that there is also a strategy in a more competitive game, 'cause there are strategies in games like football but you don't really do that much of thinking but here you can like have a good time and know like first you grab this and then this one so this team doesn't intercept it so like that. Limited resources and limited time so that makes it hard, you have to think so good thinking and good precision, so without good thinking and good precision you lose.” (Team: Colony.)

Although the problem is mentioned, the teams describe the problem very briefly. They do mention a fault with other games, e.g. “usually you just run for fun” or “you don't really do that much of (strategic) thinking”. These remarks are rather abstract and no elaborated information about the problem is given, although they did give more elaborated information on how the solution looks and works.

In all the presentations the explanation of the problem within a context was interpreted in different ways. Three of the teams used similar characteristics such as relating it to the gym, and how two types of movers wanted to play a game (“Carry the King”, “Exercise Tag” and “Scrumble”). The team “Obstacle monkeys” turned the context of the gym into a Jungle. The team “Colony” explained the problem relating it to a medieval context and when they introduced the characters they were able to narrow it down by explaining the problem along with the characters.

All teams mention the solution found, the newly designed game, and describe how it works. For example,

“Here you see over there is the map design of our game. So you can have four teams, or you could have more or less but this is how we are like designing our first draft and there are six pieces of territory lying around here and the goal of your team is to claim as much as possible. (“Team Colony”)

“Like carrying another person like in teams, they have to cross the lake as fast as they can and that's like a competition and it's fun 'cause they have to find a way to carry them the person without using hands.” (Team: Carry the King)

When they were presenting orally, the pupils also used body language to explain how their design worked. Especially, when the problem owner was asking them questions after their final presentation, all the questions focused on elaborating more on how their design worked, so they were using role play, drama and gestures to elaborate more on their design idea.

## **What was achieved in terms of supporting the pupil's ability to express the user's feelings?**

The five teams were able to introduce the characters as end users and the benefits for them. They were able to give a minimal description about them by explaining with which type of mover they identified (leisure, fitness or competition) but they were not able to focus on the feeling.

For example: “To have fun and it's competitive and also fitness because you have to pick up the person, like competitive, fun and fitness and that game has the three of them, so that makes them more persons play it.” (Team: Carry the king)

“Because you can have fun and be fit at the same time” (Team: Exercise Tag)

Here the teams indicate that the game is attractive for more children because the game is geared towards leisure, competition and fitness, but no specific user experiences or feelings are communicated. The other team (Scrumble) mainly explains the game and how it is different from existing games, but do not describe user benefits.

All teams start their presentations with either a description of the designed game or with some abstract benefits for the potential users. The problem is only briefly communicated; the solution is explained in great detail, but the benefits for the users are not described by two teams or rather abstract by the three other teams. In the



intermediate presentation none uses a narrative timeline starting with the problem and then going to the solution, rather they all start with the solution and describe some benefits of their game.

During the final presentation they follow a story plot that helps them to elaborate on the narrative of their presentation. Only one of the teams was able to mention fun as one of the end feelings as a result of their design. Two other teams were more focused on finding audience acceptance as a way to consolidate and validate their design. They were also focused on the type of end user but not necessarily on their feeling. This gives room for improvement to support the learning process focusing on the empathic part of the design related to the user's feelings.

#### **4. CONCLUSION**

Throughout the design cycle the three selected features of design language – naming, problem-solution narrative structure and paying attention to user feelings - can be modeled or supported using the curriculum cycle loosely: for instance first modeling (teacher-led), then joint construction and pupil-led construction using features of the design language. As our case-study shows, a lot of modeling and supporting can be done with material from the design project the pupils are working on, making working on design communication authentic and motivating.

The narrative structure was used as the plot to present the problem-solution scenario and the pupils were able to accomplish it, although there was not enough elaboration of the user's emotions in their design presentation.

For future research there needs to be improvement of the intervention in this direction in order to support the learning process focusing on the empathic part of the design related to the user's feelings. It would also be interesting to consider an improvement in the key features of the pupil narrative to focus more on the problem-solution scenario.

The case-study also shows that pupils may also demonstrate to other pupils elements of the design genre as they spontaneously use and develop design language. The use of gestures, drama and prototypes was not modeled beforehand by the teacher, but good examples were spontaneously present. Especially, during the final presentation, when the problem owner asked them to elaborate more on how their design worked. The feedback process could achieve a full potential by also bridging the communication language that the problem owner uses to give feedback with the language the pupils are using to present their design ideas. We advise teachers to think of ways to make use of these occurrences so the class can learn from natural approaches of children when presenting their design ideas. Therefore, we stimulate the teacher to encourage pupils to present using body language and consider it as part of the final outcome when presenting their design idea.

A limitation of the genre-pedagogic cycle as a tool to support to design language is found in the fact that its set-up is primarily driven by language goals. The focus is on one specific genre and pupils learn about this genre by analyzing and applying the same genre over and over again while working on several topics. However, a design project focuses on one topic (in our case gym) and includes many genres (e.g. the genre of brainstorming, the genre of sketching etc). This contradiction was solved in the case study by introducing video's on other designs and by applying the genre-cycle loosely in the context of the design cycle. As a result a lot of modelling and support around design presentations was done with authentic material from the gym design project.

#### **5. ACKNOWLEDGMENTS**

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## 7. APPENDIX

Category	Questions in worksheet
Naming the design	Name of the sport activity (make the title catchy and easy to pronounce)
Problem- solution scenario	Describe the sport activity: (purpose, how it starts, rules, how it ends)
	Why do you think it’s a good sport activity? How does it help to raise the heartbeat?
	Highlight the details that make it a “new” sport activity:
	What type of materials do you need?
End User	Visual design of your sport activity:
	Who plays it? For which type of movers is it meant for?

# Attention and Action during the Design and Technology Lesson: by fine-tuning task characteristics

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In this paper, pupils' design behaviour is regarded as an expression of active knowledge acquisition. Four cases of building a task structure, which supports effective discovery learning, were investigated. We focus on simple characteristics in a model to explain the effects of the structure on task execution. It reconciles the advantages of direct instruction and constructionism. The model offers an easy way to immediately denote pupils' behaviour during the lesson. The idea is that the model can function as a heuristic and becomes manageable for use by the teacher during the lesson. In this way it strongly serves formative evaluation. In the first case we observed the following characteristics of the task underpinning attentive and active design behaviour:

- Success criteria formulated during task instruction, guided performance and evaluation
- The task was both challenging and doable
- A joint evaluation of performance results and methods that concluded the task led to shared knowledge and language

In the second case, we researched the effect of enhancing skilfulness of focused observation on the quality of discovery and subsequent invention. In the third case, we observed that a familiar situation benefitted the start of the performance. However, the absence of a joint evaluation led to limited shared knowledge and shared language regarding the task. This hindered pupil's rise of clear expectations about the expected results. In the last case, we researched the effect of enhancing skilfulness of analysis on the quality of verbal expression of discovery and subsequent invention. The thinking hats of De Bono were used as instruments to express ideas about a cuddly toy. The four cases together resulted in a simple model based on task characteristics that furthers active discovery and invention.

*Key Words: D&T task, pupil autonomy, class language, joint evaluation, Montessori principles.*

## 1. INTRODUCTION AND LITERATURE



*Figure 1. Attentive behaviour during the D&T lesson*

A generally heard difficulty during Design & Technology education is the accomplishment of prolonged attentive and active behaviour of the pupils. The consequence of this is a failed lesson, because attentive and active behaviour is necessary for getting fresh ideas and motivation to reconstruct former ideas. This difficulty might be the result of ineffective use of either “direct instruction” or “constructionism”.

Direct instruction benefits clearness for pupils about the aim of a lesson, but can hinder pupil’s natural learning process (Gopnik, 2012).

Constructionism benefits the interaction of the hand and the mind (Papert & Harel, 1991), but can lack guidance towards learning goals (Kirschner, Sweller, Clark, 2006).

Natural learning is benefitted by using direct instruction in a coaching way. By using a collection of design tasks, control can be exercised subtle through restrictions built into these design tasks (Kimbell, 1994). Also Sennett (2009) makes clear that one job can be seen as a collection of many tasks, by emphasizing the significance of details; e.g. the grip on the pencil, the pressure on the chisel. To accomplish this, one lesson can be transformed into multiple events. One event can be used to introduce the point of the lesson, to control insight and activate former knowledge. Then, the other events can be used to instruct pupils on specific challenges, accompanied by clear expectations about outcomes. Joint evaluation of an event to create joint insights accompanied by joint language can function as a base for a next event (Lemke, 2000; Mercer, 2013; Black & Wiliam, 2009).

Guidance during constructionism can be found in borders combined with facilitation. Teachers in the Montessori tradition (Montessori, 1912) continuously work on familiar borders, where within pupils can autonomously discover and practice resulting in simultaneous designing and knowledge acquisition. The importance of knowledge gained by experience as an anchor for abstract thinking is recently confirmed by Hayes & Kraemer (2017). Sennett (2009) arguments that doing a job properly takes the time it takes. While we are working, submerged processes of thought and feeling are in progress.

A bordered task also protects pupils against overwhelm, that stops them to learn (Dewey, 1910). Keeping the task small and manageable, accompanied by clear expectations about the outcomes, is a way to border a task. This is in accordance with the ideas of Vygotsky (1978), who argues that the function of an educational task is to create a bounded “cognitive conflict” in the pupils. An unbounded cognitive conflict can result in passiveness or frustration, whereas a bounded cognitive conflict initiates reconsideration of ideas. Thus, the clarity of a task is of importance.

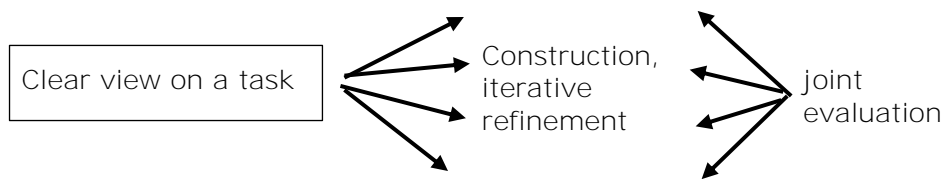


Figure 2. Construction and iterative refinement are furthered by a clear view on a task and joint evaluation.

## 2. METHODOLOGY

In this paper, we focus on that characteristics of tasks leading to a clear view on tasks. The results of our case-studies are described and combined to provide an overview of task elements activating pupils and leading to discovery and invention.

The central research question is: “*What are beneficial characteristics of the structure of a task allowing pupils to learn through discovery?*”

We explored four cases. Important questions were: “What do pupils need to start discovery?”, “What do pupils need to start invention?”

An important feature of all cases was the exploration of unusual educational situations by questions such as “What will happen if the pupils have to collaborate with a non-chosen partner?” or “What will happen if the teacher doesn’t intervene at all during the lesson?” or “What will happen when the teacher asks the pupils (4-6 year olds) to look at an object for a long time?” or “What will happen with the verbal expression of 4-6 year olds, when the teacher offers an instrument for deconstructing complexity”?

All cases encompassed three periods, which allowed the separate exploration of different conditions. A side effect of the use of three periods during all four case studies was that pupils’ knowledge and skills increased along the way (Pirttimaa, Husu & Metsärinne, 2017). Each case is reported below, describing the task and accompanying discovery behaviour.

## **2.1. Case study 1: The marble-boat**

### *2.1.1. The task*

Five Montessori principles were selected to shape this design assignment: freedom of choice, self-checking, iteration, collaboration and presentation. The pupils (6-8 year olds) were given the task: “Fold a piece of aluminium foil so it can hold the weight of marbles when it lies on the water. The more marbles it can hold, the better.” By counting the number of marbles, the pupils could check the result themselves.

The same assignment was given three times with minor variations. The first time, the pupils had to work in self chosen pairs. The second time, the pupils had to work in non-chosen pairs, the third time they had free choice in working alone or in self chosen pairs and in carrying out the task or not. They could use their initiative to present their boat for a video-camera. A joint presentation of intermediate boats together with reflection at the end of each period was added to the Montessori conditions with the objective to set the task for the next period. See Looijenga, Klapwijk, de Vries (2015) for a complete description of the case-study.

### *2.1.2. Discovery behaviour of the pupils*

The task was clear to all students quickly. The situation did not require unmastered skills and made all pupils start the performance easily. The iterated task gave the following results: the pupils showed an increasing sense of control and an increasing detailed insight in what to do for maximum results during the three work periods. Because of their focus on the explicit criterium for success (Clarke, 2001); “make a boat that can hold as many marbles as possible without sinking.”, they gained insight into the causal link between the size of the surface that has to hold the marbles, and the number of marbles held. The pupils refined their insights by looking at each other and talking together. It stimulated continued building and testing. The joint presentation of and reflection on the intermediate boats led to reasoning. Working together with a non-chosen partner in the second work period did not stimulate active and enthusiastic behaviour, albeit joint evaluation showed increased insight. Most pupils were motivated to go on iterating until they reached conscious insight. A few pupils continued building and testing new marble carriers until they reached very high, near maximum results.



*Figure 3. Boat holding 360 marbles*

### *2.1.3. Conclusions*

The simple, challenging task and the familiar situation, together with the clear expectations not only furthered discovery and invention skills in the pupils, but also collaboration and interaction during the performance of the task. In addition, the task structure served the joint presentation of and the reflection on the (intermediate) boats.

The teacher had ample opportunity to observe.

Additional literature about capacity (Dewey, 1910) capability, development and metacognition (Zohar & Dori, 2012, pp. 1-19), confirmed the relationship between the way the task was structured and the observed results.

In short; the beneficial task characteristics were:

- giving a simple and challenging task,
- focusing on a familiar situation,
- including simple and clear criteria for successful performance.

### *2.1.4. Next question*

The results showed that collaboration and interaction during the performance of a task are important. But are they sufficient to enable aimed discovery and invention?

## **2.2. Case study 2: How to be an explorer of the world**

### *2.2.1. The task*

The explorations in the book of Keri Smith were chosen to practice observation. Keri's unusual well defined criteria for successful observations easily lead to fresh views, resulting in discovery (Keri Smith, 2008), also with very young pupils (4-6 year olds).

In three periods, the pupils experienced three different explorations.

The first exploration was about discovering unseen things in familiar surroundings (the classroom). A whole week long, this exercise was practical applied in discovering things to tidy up.

The next exploration was about being/becoming a real artist. A real artist is very skilled in ordinary things, like washing up, setting the table for dinner, comforting your little brother, helping other pupils and so on. The whole week, the pupils tried to become real artists in as many activities as possible.

The last exploration was about observing a familiar object for a long time until new aspects were discovered. This exploration was also applied in class. When a pupil showed boredom or could not make a choice for a particular activity, the teacher invited the pupil to observe longer until something to do was found.



*Figure 4. Discovering unseen things in familiar surroundings.*  
The complete case is described by Looijenga et al. (2017a).



*Figure 5. Observing a familiar object for a long time.*

### *2.2.2. Discovery behaviour of the pupils*

Each task was simply and clearly verbalised and demonstrated by the teacher. During the joint activities, all pupils were actively participating in a quiet and attentive way. Individually, the pupils reacted adequately and started discovery behaviour on interaction between pupil and teacher about the subject.

### *2.2.3. Conclusions*

The situation was familiar and did not require unmastered skills. Each task was doable and challenging, because of the detailed description of the unusual criteria for successful observation such as “observe until you are no longer bored”. The explorations were a great success in starting discovery behaviour. From this case we learned that even these young pupils are capable of a lot more than we think. Through practice, they became skilled in broad application of detailed observation, resulting in a calm approach of all sorts of tasks.

In short; the beneficial characteristics of the structure of the task were:

- giving a simple task,
- working towards skillfulness,
- including precise criteria for successful observation.

### *2.2.4. Next question*

The results showed that practice can change inability in ability. But is a simple task in a familiar situation sufficient to start discovery and invention? Or is additional intervention of the teacher required?

## **2.3. Case study 3: Wheels at work**

### *2.3.1. The task*

The issue of this design assignment was about wheels and leverage. A week before, a demonstration was given of lifting a weight from the floor, hanging at the end of a rope. First, the teacher was standing on a chair, so that the rope was longer. Then, the teacher was standing on the floor and the rope was shortened. Forty pupils (6 to 9 year olds) explored hands on a circuit with “machines” searching for answers to the question “What requires more effort; lifting a weight on a long rope or on a shortened rope?”.

The same assignment was given three times.

The first time, the “machines” in the circuit were simple, e.g. cork screw, pulleys, K’nex, windlass. The second time the “machines” in the circuit were complex, e.g. waterwheel, windmill, pinwheel, music machine. The third time the children had to make a self-created “machine”.



Figure 6. Simple machines



Figure 8. Self created machine



Figure 7. Complex machine

Because an aim of this study was researching the effect of handling without teacher intervention, there was no intermediate evaluation at the end of each lesson.

The complete case is described by Looijenga, Klapwijk, De Vries (2017a)

### 2.3.2. Discovery behaviour of the pupils

The task was quickly clear to all students. It appeared that all pupils found a starting point for their search. Even generally passive pupils started exploring without any encouragement from the teacher. They started their exploration with a familiar object, a corkscrew or hand drill. After this groundwork, they kept on going. We learned that even passive pupils would reach an active discovery state by providing them with household objects and by giving them time to discover.



Both circuits evoked in all pupils' active exploratory behaviour.

The success of making self-created "machines" in the third period was relatively poor.

### 2.3.3. Conclusions

The results clearly show the positive effect of a simple and challenging task, accompanied by a familiar situation. The task was specified by the demonstration and the accompanying question. The familiar situation activated all pupils to discover and try fresh ideas. However, the absent evaluation led to this striking detail: the pupils did not develop spoken language. They showed insight by means of actions and gestures, not words. Another effect of the absent joint evaluation was the relative failure of making self-created "machines". Apparently the pupils had a fuzzy view of what the teacher expected of them.

This proves that intervention by the teacher towards shared reasoning and shared language is necessary to take a next step in discovery and invention. The lack of a teacher's intervention in the third period of the activity led to the prevention of the onset of designing, because shared language is required to build clear expectations.

In short; the beneficial characteristics of the structure of the task were:

- giving a simple and challenging task
- focusing on a familiar situation

### 2.3.4. Next question

The results showed that clear expectations are important for carrying out a task. In this case, the expectations appeared to be vague in the last period due to the lack of shared language. Expectations can be vague, but they can also be too complex. When pupils lack analysis skills, they are incapable of handling complex expectations of the teacher. How can we practice analysis skills?

## 2.4. Case study 3: The thinking hats

### 2.4.1. The task

The thinking hats of De Bono were chosen as an instrument to handle analysis. The six different coloured hats are connected to specified views on a subject. We used the factual, positive, negative, emotional and creative points of view to practice the rules and means of expression on a cuddly toy. The teacher had the overall view and scaffolded the use of specific language, accompanying specific hats. This was done by repeated use of specific words when inviting pupils to tell about the cuddly toy. When expression got stuck, the teacher always asked the same questions (More? Another hat?) to help the pupil to keep on going. The pupils themselves decided how much and in what way they spoke about the cuddly toy.



Figure 9. De Bono's thinking hats

The case encompassed three periods: demonstration, practice for camera with an unfamiliar cuddly toy and after that with a familiar cuddly toy. See Looijenga, Klapwijk, de Vries (2017b) for a complete description of the case-study.

#### *2.4.2. Discovery behaviour of the pupils*

The task accompanied by scaffolding language supported the pupils in becoming expressively and verbally informative. The hats provided a structure that enabled the pupils to get and express varied ideas about their familiar cuddly toy. A structure in which other complex subjects could be discussed, was set.

At the start familiarity with analysing with the hats and the accompanying words was poor. Nevertheless, during the third period, some pupils reached such a level of analysing that they started to discover and to invent new ideas.

#### *2.4.3. Conclusions*

The task to tell about the cuddly toy from one specific view, suggested by a hat, was unambiguous. The object was familiar. The challenge was analysing the subject from specific points of view with accompanied verbalisation. During practicing, both mastering of and familiarity with all points of view were growing for all pupils.

The results show that the level of familiarity with the cuddly toy affected the clearness of the point of view. The unfamiliar cuddly toy and the class cuddly toy evoked expression of uncomfortable feelings. Scaffolded, the pupils managed to express themselves clearly and class developed shared language about analysis using different perspectives (the five De Bono hats).

In short; the beneficial characteristics of the structure of the task were:

- giving a simple task,
- scaffolded working toward skilfulness,
- including unambiguous criteria for successful analysis

### **3. OVERALL CONCLUSION**

To answer the central research question: The four cases show that a task allowing pupils to learn through discovery is based on:

- Simplicity of the task
- Familiarity of the situation in which the task is performed (including all required skills!)

And defined by:

- Simple and clear criteria for a successful performance of the task

Together these characteristics ensure a clear view on the task.

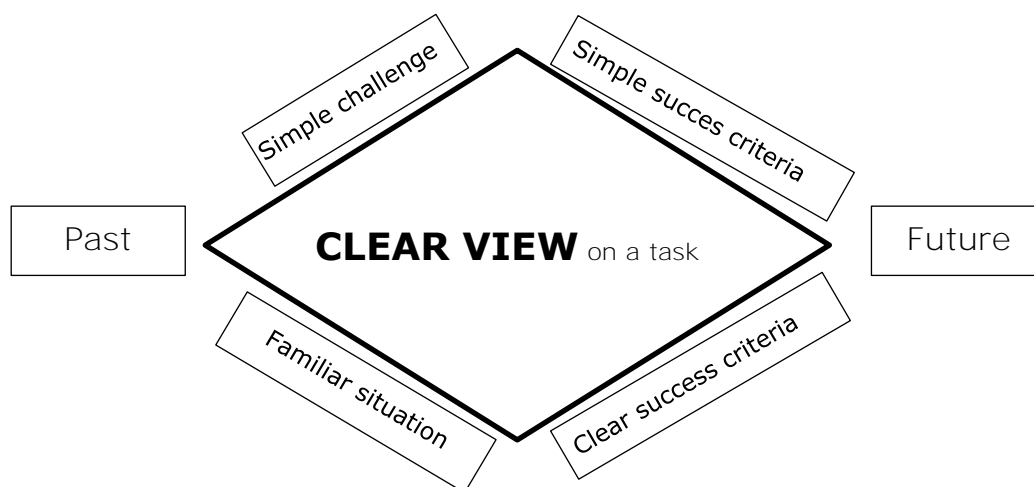


Figure 10. Task-structure supporting a clear view

## 4. DISCUSSION

### 4.1. Limitations

These case-studies took place on a Montessori school with a tradition of valuing pupil's autonomous behaviour. When pupils are not used to autonomous acting, they might need adaptation of tasks or separate rehearsal of skills furthering autonomous behaviour.

### 4.2. Implications

Recently, a lot of attention has been paid to the value of clear and simple success criteria due to the work of Hattie (2012), and Black and Wiliam (2009) on formative evaluation.

The notion of doability has been less central lately, but not less important. To resolve the dilemma of offering a challenge and avoiding unfamiliarity, Dewey (1938) recommends to build on existing knowledge and experience. A familiar situation encompasses knowledge and skills. Sennett (2009) points out the significance of specific abilities within a task. Unfamiliarity with specific abilities, needed to accomplish the task, can lead to frustration and passiveness. Through the adaptation of the learning situation it is possible to build on pupil's experiences as well as to promote positive skills and dispositions (Creative Little Scientists, 2014).

The simple structure can be used by teachers on the fly during their design and technology lessons as well as elsewhere. Whenever teachers observe that pupils are not attentive and active during task performance, they can conclude that a clear view is absent and use the structure to find out the cause of the passiveness. Do the pupils have the required abilities, does the task include a doable challenge, do they know what to do?

Currently there are many good Design and Technology lessons on the market, but they have the format of one big procedure. This format creates confusion for teachers. We concluded that attentive and active pupils are the result of an appropriate supply of tasks. This implicates, that a complicated project needs a split into several doable tasks. Support from teaching methodology designers can help teachers to achieve this. Therefore further research into possibilities for abovementioned support might be useful.

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# Interdisciplinary Teaching in Swedish Primary Schools: Teachers' Perspectives of Subject-Matter Integration in Technology and History

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Technology is a compulsory subject for all grades in Sweden. The curriculum states that teaching should contribute to the students' understanding of technological development (LGr11, syllabus in technology). Although interdisciplinary teaching is encouraged in the curriculum, the relationship between subject matter in technology and history is not well documented. In this study, five primary school teachers' experiences and attitudes towards interdisciplinary teaching are investigated through open-ended interviews. A thematic analysis of the data identifies three preliminary themes. The first theme confirms that interdisciplinary teaching occurs. The teachers say that through interdisciplinary teaching, they build meaningfulness and coherence for students. In the second theme, teaching on technological development often happens spontaneously. Here, teachers became aware during the interview that their teaching may also be described as technological. The third theme suggests that, for students' immersion and understanding, teachers use artefacts to access the past. Interdisciplinary teaching between technology and history is largely unexplored, especially at the lower grades. By identifying that, in teaching practice, technology is integrated with history—although not always planned or consciously—a growing awareness of the subject of technology will result in a stronger position in the curriculum and in wider contexts.

*Key Words: Interdisciplinary teaching, Technology education, Technology and history, Teachers' perspectives, Swedish primary schools.*

## 1. INTRODUCTION

According to the overall goals and guidelines in the Swedish curriculum, teachers should, among other requirements, give students the opportunity to do 'interdisciplinary' work (Skolverket, 2011a /16, chapter 2, p. 14). Even so, the national curriculum (ref Skolverket 2011a/16) is divided into subjects, for example, mathematics, Swedish, history, and technology, and each subject has an independent syllabus.

This study investigates how five primary school teachers in Sweden integrate technology and history. The teachers describe their practice of interdisciplinary teaching in relation to the curriculum and other factors. By interdisciplinary teaching, we mean that, during the same lesson, they address core content and/or purposes of more than one subject. The development of school subjects is closely linked to social development and varying knowledge and science ideals (Linde, 2012; Lindquist, 1987). In the Swedish curriculum debate, a tradition of progressive thinking has been influenced and linked to thematic interaction and a holistic view. However, there are contradictions in the approach and different ways to handle content (Linde, 2012). Bernstein talks about two different codes for the organisation of subjects in curriculum theory (Bernstein, 1971, Linde, 2012). In the 'collection code', Bernstein suggests that the subjects are defined according to the academic disciplines. The teachers in that code self-identify as subject representatives. 'Integrative code' means that there are other entities than the subject that are cohesive, for example, the class, the team, or overall themes. The studies are thematic, and the teachers cooperate. The teachers within that code self-identify more as educators than as representatives of a discipline.

Interdisciplinary teaching has long been discussed in Sweden (Svingby, 1986). Internationally, variations of integrative, holistic, or interdisciplinary curricula have been used and discussed (Vars, 1991; Lenoir, 2006).

Interdisciplinary teaching in science, technology, engineering and mathematics (STEM)<sup>6</sup> subjects has been well researched both nationally and internationally (cf. Persson et al., 2009). An interventional study from the United States showed that it benefits students' interest in these subjects, however, it is a challenge to get teachers to adopt this approach. (Al Salami et al., 2017). A British project investigated how middle school teachers worked with the topic 'Mountains on the moon' to have their students learn about the development of the telescope and the discovery of mountains on the moon (Solomon et al., 1992).

The literature addresses interdisciplinary teaching primarily concerning older students, in terms of case studies or problem solving in which social science plays an important role (e.g. Blanck, 2014). Similarly, Bossler (2018) studies the teaching of natural science based on social issues. Examples of interdisciplinary teaching can be found in the Common Core Era. This is an American initiative on common subject core in mathematics and English to raise student results and initiate critical thinking among students. In that effort, many teachers seem to combine project-based interdisciplinary learning with new technology. For example, in the iGarden project, teachers combine social studies, language arts, mathematics, and science together in a hands-on, inquiry-based unit (Cavin et al., 2014). In yet another example, a development project from the 1960s tested technology (in terms of technical orientation), as it was considered particularly suitable for resolving boundaries between subjects (Hultén, 2011). In design, some projects are described with an interdisciplinary character, but also mostly for pupils in their teens. For younger students, there are interdisciplinary projects that often involve physical activities (e.g. Gortmaker et al., 1999). Regarding the younger students, the integration of some subjects seems to be more explored than others. For example, many students of teaching write about how mathematics is managed trans-disciplinarily (e.g. Johansson et al., 2006).

The present study has a focus that, according to this first examination, is unexplored. Neither technology for the youngest students nor technology in social study subjects is well documented. This study can contribute to and open up further issues.

The aim of the study is to broaden, develop, and strengthen the teaching of technology and technological-historical approaches. The study investigates the different experiences and attitudes the respondents conveyed in terms of interdisciplinary teaching of technology and history. Our research questions were:

- What is expressed by teachers about their interdisciplinary teaching of the subject of technology and other subjects?
- What do the teachers express about their teaching that deals with technological development?

## 2. THE SWEDISH CURRICULUM

A brief description of the Swedish curriculum (Skolverket (2011a/2016) explains how subjects are organised in schools and how they relate to each other. Chapters 1 and 2 deal with value bases and the overall goals and guidelines. The term 'interdisciplinary' is found as a guideline for teachers and principals, but also as the requirement to provide students with an overview and context, which can be interpreted as working towards subject-based approaches. The third part of the curriculum is the syllabus. Each subject is described in three parts. The first part consists of a target text for each subject, which formulates the subject-specific overall purpose of the study of the subject in elementary school. The next part is the central content, which is the subject's substantive content, reported in the form of a sentence. The central content for Grades 1–3 is different from the higher grade levels in that all the elements in the social study subjects<sup>7</sup> (called SO) are presented in a single block. This also applies to natural science studies<sup>8</sup> (called NO). Technology is written independently. It has its own purpose, as do all subjects, but also its own central content for all grades. Interdisciplinary teaching seems to be mainly mandated between the SO subjects and the NO subjects at the elementary level through the co-written subjects' contents. But with the subject of technology, an interdisciplinary approach is offered. "Technology and technological change" is the subject of a school's in-depth subject didactic texts on the central content of technology (Skolverket, n.d.). It emphasises that the primary purpose of technology education is contributing to the students' understanding of how technology evolves over time and how this development can

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<sup>6</sup> Science, Technology, Engineering, Mathematics

be explained. Many examples from history are given. However, no subject description or interdisciplinary teaching is mentioned or problematized.

There are difficulties in how this expression takes form. The idea is that integrated education concerns teaching activities in which subject boundaries are insignificant, while the requirements are for teachers to assess the goals for the groups of subjects in SO and NO. We see the potential of investigating the presence of relationships between subjects that teachers teach to create understanding and comprehension. Our area of interest lies in investigating the existence of interdisciplinary teaching between history, a subject belonging to the SO block, and the independently written technology subject.

### 3. METHOD

The study is based on a socio-cultural learning perspective, as the teachers' statements are based on their socio-cultural experiences in the time and environment they live and work (e.g. Säljö, 2014). Our understanding-based approach has implicated a qualitative interview study. Four informants were interviewed via Skype (Internet media). This enabled a geographically wider selection of respondents. The fifth person was interviewed face-to-face. The interviews were semi-structured (Robson & McCartan, 2016).

The respondents are active teachers who teach Grades 1 through 3, except for 'Anna', who was retired. The selection of respondents was a convenience choice (appeal through social media), in addition to the choice of Anna, who was strategically chosen to represent a previous approach. The selection is not representative but gives a variety of differences and similarities. The selection and the possible option of general reasoning conclusions will be discussed in a future study.

*Table 1. List of respondents (fictitious names).*

<b>Respondents</b>	<b>Teacher education/ Education in technology</b>	<b>Teacher's years of experience</b>	<b>School location, organisation</b>
Eva	Grades 1–7/ for Grades 1–3	5 years	Urban, independent school
Sanna	Grade 1–7/ for Grades 1–3	2 years	Same as above
Pia	Grade 1–7, Swedish, social science/ No technology education	13 years	Small town, central Sweden, municipal administration
Jeanette	Grades 1–7, math, science, technology/Grades 1–7	5 years	Small town, southern Sweden, municipal administration
Anna	Primary school teacher/ shorter further educations Grades 1–3	43 years	Inner city school, metropolitan area, municipal administration

The documentation comprises audio recordings that were transcribed in a somewhat edited form. The analysis was inspired by the grounded theory approach. (e.g. Hallström et al., 2014). According to Robson and McCartan (2016), grounded theory has three stages. First, the researcher finds conceptual categories in the data, and then searches for relationships between these categories. Subsequently, core concepts arise, in which the material is brought together and described for relationships between core concepts and other research. In the analysis work, three preliminary core concepts emerged: interdisciplinary teaching in practice, the spontaneous addressing of technological developments, and artefacts providing access to historical awareness.

<sup>7</sup> The subjects are religion, social sciences, history, and geography

<sup>8</sup> The subjects are physics, chemistry, and biology

## 4. RESULTS

### 4.1. *Interdisciplinary teaching in practice*

The teachers all confirmed the interdisciplinary teaching, meaning that, during the same lesson, they addressed central content and/or purposes from more than one subject. The interviews initially asked for integration with other subjects, after which the questions were addressed to integration of social science subjects (SO subjects) and history. The results show that the integration between technology and natural science subjects (NO subjects) is considered natural, by some. That connection is more conscious and clear: Eva explains that it depends on how the subjects were handled in her education:

Associated with NO, because of how it is presented at the university. And read together, becomes a natural link. (Eva)

The first things you associate, naturally. (Jeanette)

NO is considered to be more naturally linked to the subject of technology by Eva, Sanna, and Jeanette. These three have a more recent teacher education degree, so that indicates the relevance in Eva's explanation about the impact of her education. Eva believes that the nature-oriented subjects have a more systematic approach, which she feels is easier to use with the students. This way is to present hypotheses and work chronologically. Eva also applies this systematic approach in other subjects, such as reading comprehension. Thus, the system of NO is applied rather than the subject content. Pia, in contrast, is opposed to the connection between NO and technology. Pia's teacher training occurred earlier than the other three, and is more specialised towards Swedish and social study subjects. She thinks technology does not need to belong to NO block. She brings up the everyday technology she has taught the class, about swinging boards and traffic, and how traffic rules have been adapted based on technological changes. For her, the integration of technology with SO is equally natural to that with NO.

Further discussions show that the division into school subjects does not seem to be the primary division. A teacher believes that it is important to teach one thing at a time, but not necessarily one subject at a time. They see no purpose in distinguishing and naming the subjects for the students. Anna and Pia say:

They [the children] do not think that way, and I do not think that way. (Anna)

Try to 'bake' together, I think, in larger themes. (Pia)

Jeanette thinks it is good to point out that what has been taught is technology, because:

It is useful to say, so as not to be afraid [of the subject] when they grow older, they are good. (Jeanette)

She thinks by naming it, she counteracts the students' impression that technology is difficult. Students get the opportunity to discover that they are knowledgeable in the subject.

Teachers believe that they build meaningfulness and coherence by integrating subjects. Sometimes they separate and clarify the school subjects for the students, but this is done during another lesson, aimed at processing and clarifying the knowledge requirements. This is also done by the teacher in assessments, or when they document the teaching.

Afterwards, when I assess the activity or when I write down a bit of what we learned and what we were talking about, then I try to be aware that it became technology and documented it in a way. (Pia)



Here, Pia also raises another subject: how the purpose and central content of the technology syllabus can be spontaneous and unplanned in teaching.

#### ***4.2. Spontaneous addressing of technological developments***

In describing how they can come up with technological developments in the classroom, teachers say it is often by chance or because students' questions guide them. Teachers use expressions that indicate they end up teaching the history of technology or technological development without having planned it in advance. For example:

Slips in, gets over, gets quite aware... (Sanna)

I do, though, but not really planned. That's the crazy thing about it, that it comes spontaneously. (Pia)

I try to be aware of it in retrospect and documenting in some way. (Eva)

Pia further says that when she is in another subject, she usually borrows what the children think is exciting. She borrowed the example of the theme "The farm" (NO). She mentions that it covered a lot of history, including how farms were managed in the old days (HI).

And it is technology, usually it comes in technology, also for that part [...] in the context, get inspiration, when in other words when comparing spontaneously, shows up, the technology... (Pia)

The teachers are guided into technology, for example, by the children's questions about artefacts from the teacher's childhood. Also in learning activities, they slide into teaching about a historical object and compare it with the present.

#### ***4.3. Artefacts providing access to historical awareness***

Showing typical things for each era, you have to look at how they lived, and that includes technological development. (Eva)

Eva expresses how she emphasises the way objects can provide access to historical consciousness. She describes how she sees technological development in things and this as a part of the knowledge of how they lived their everyday life.

The teachers' use of artefacts can be seen as an entrance to the past. The term "typical things" implies that Eva discerns key objects that can be used to clarify. Sanna exemplifies with the wheels, and then says in the same sentence 'how you travelled'. She connects the artefact's function, as an explanation for why she specifies a precise object. It seems that the artefact is usually mentioned only once a sociotechnical context has already been defined. But sometimes the function is mentioned first. When Anna described her theme "How did we get fire?" she first talked about tinder and 'a fire-bow'. The students got to try this technology. The purpose for letting students try ancient technology appears to be creating immersion and understanding. A teacher says that the students then

notice that it is not so terribly easy. (Pia)

The question of whether artefacts are a goal or a means requires deeper analysis.

### **5. DISCUSSION**

This study investigates how primary school teachers describe how they do interdisciplinary teaching, defined as during the same lesson, they addressed central content and/or purposes deal with more than one subject of study. From their responses, three interesting themes emerged.

First, these teachers confirm that interdisciplinary teaching occurs. They describe their teaching primarily by talking about themes, where school subjects are integrated, meaning they build meaningfulness and understanding of the whole. In another kind of lesson, they separate and clarify the school subjects for the students. This is done for documentation and assessment according to the knowledge requirements.

Here we see how the teachers balance the contradiction between, on the one hand, following the curriculum recommendations in Chapters 1 and 2 of the Swedish national curriculum (Skolverket (2011a/2016). 2011) in terms of “interdisciplinary” and the requirement to provide students with an overview and context. On the other hand, these teachers are trying to fulfil the requirements to assess the goals in the individual subjects, which are expressed in the central contexts and the knowledge standards in the curriculum.

One way of explaining how primary school teachers integrate subjects can be to use terminology from curriculum theory. Bernstein (1971) referred to two different codes in curriculum theory. In the ‘collection code’, the subjects correspond to academic disciplines. In the ‘integrative code’, the emphasis is on other entities, such as overall themes. The attitudes of the interviewed teachers, the organisation of the elementary school, and subjects presented in a single block in the curriculum indicate that the teachers can be considered to adhere to the ‘integrative code’.

In the second theme, teaching on technological developments emerges as unplanned. To some extent, this is an interview effect. The teachers become aware during the interview that the examples they described could also be seen as teaching technology. Afterwards, they could relate their teaching to some of the central content from the curriculum, and as researchers, we can relate their activities to the purposes of the subject. Now it becomes interesting to discuss the definitions of technology. Is the curriculum unclear in relation to how technology occurs in different contexts? Does it depend on who you are and what education you have to determine how you define technology? Are there different views on how contextual technology should be considered as technology education? This is of interest to further explore in future studies. Another interview effect was also the spontaneous expression of bad conscience that the interview questions gave rise to, which may confirm the report of the Swedish School Inspectorate. Several of the teachers expressed that they have taught too little technology, as it had become *too little construction* (Sanna). This is also related to the discussion of the definition of technology as a subject in which you construct things.

The third theme suggests that teachers use artefacts for immersion and understanding. Are there recurring key objects? Is there a kind of canon of meaning-bearing and knowledge-bearing objects, which many teachers return to when teaching the story of ‘the old days’? These are questions we will take with us into the next phase of the project, which is a classroom study. After this study on the teachers’ intentions, we will use classroom exploration to discover how interdisciplinary teaching in history and technology is appearing and manifested in practice. The teachers’ use of artefacts as carriers of knowledge delineates an interesting path for future study.

In the study, we examined five teachers’ statements about the occurrence of technology in history. That particular connection is largely unexplored, especially at the lower grade levels. By demonstrating that technology is taught integrated with history, although sometimes unplanned and subconsciously, the subject of technology can be given a stronger position in a wider context.

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# A Preliminary Model of Problem Categorisation to Explore the Cognitive Abilities Required for Problem Solving in Engineering Education

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The provision of engineering education as a means of enabling students to develop contemporary transversal competencies such as problem solving, critical thinking, adaptive reasoning and communication, places a responsibility on curriculum designers to reposition these aptitudes within the hierarchy of desired skills. Problem solving is a fundamental attribute of each engineering discipline and plays a pivotal role in the work of an engineer. Problem solving is highlighted as a higher-order cognitive task that engages actions and thoughts, which prompts this investigation of it through a cognitive lens. With consideration of the range of abilities contributing to an individual's general cognitive ability, the likely cognitive abilities necessary for successful problem solving are explored and positioned within the context of engineering education and the broader engineering profession. The problems faced by engineers differ through a variety of means. Problems can vary from well- to ill-defined, and through the requirement of reflective or active means to solve them. It is proposed that the cognitive abilities necessary to problem solve vary depending on these factors. A model is presented which aims to support the identification of the cognitive abilities necessary for problem solving in consideration of the nature of and approach taken to solving a problem. Through consideration of these elements, the model aims to support engineering education and industrial training programs in addressing the skills gaps that have emerged through the advancements of technology and society.

*Key Words: Engineering Education, Problem Solving, Cognitive Abilities.*

## 1. INTRODUCTION

Problem solving is highlighted as a higher-order cognitive task (Hambrick & Oswald, 2005), however, there are a number of additional elements that may impact on an individual's problem solving performance. These influences include behaviours (Warden & Mackinnon, 2009), information processing (Cronin & Weingart, 2007), and personality (Hargadon & Bechky, 2006), which are also notable factors to be considered when exploring an individual's cognitive ability (Lubinski, 2004) and capacity to acquire skills (Kanfer & Ackerman, 1989). Considering problem solving as a solely cognitive task would be an oversight of these varying factors that contribute to an individual's performance. However, this is often necessary in individual studies to advance the pertinent remit of knowledge. Accordingly, though there are many elements that are important for problem solving. One of which, the cognitive abilities required for problem solving, is the focus of this paper.

In exploring problem solving, it is important to consider the cognitive processes that lead to the development of a solution, more specifically, the cognitive abilities that an individual requires to solve a problem. General cognitive ability ( $g$ ), refers to the differences in individual capacity to learn or process information (Kanfer & Ackerman, 1989). Individuals with high levels of  $g$  can represent more information in working memory than those with lower levels of  $g$ , resulting in individuals with higher levels being able to learn from their experiences at an advanced pace (LePine, Colquitt & Erez, 2000). There are a wide range of broad and narrow abilities, which are discussed in more detail later in this paper, that contribute to general cognitive ability (Schneider & McGrew, 2012). Therefore, numerous cognitive abilities are required to solve a complex problem such as those that exist in engineering, and it is important to identify these to facilitate respective pedagogical advances.

While exploring the cognitive abilities used in the development of a solution to a problem, the means through which information is presented and investigated must be considered. The approach taken to reach a solution to a problem will vary depending on the problem domain, type, processes needed to solve it, and the means through which a solution is conveyed (Jonassen, 1997). With such demands being placed on working memory in this situation cognitive load must also be considered. Cognitive load describes the amount of mental effort used during a task (Sweller, 1988). This occurs in the working memory due to its limitations (Kirschner, Sweller & Clark, 2016). As an individual has working memory limitations and does not have an infinite storage capacity, mental effort or strain is experienced (Paas, Renkl & Sweller, 2003).

Through experiencing excessive cognitive load, cognitive processing abilities may be impacted, therefore, hindering an individual's performance and the development of problem solutions (Pass, Renkl & Sweller, 2004; Sweller, 1988). In order for individual's to succeed in society and in their desired profession, such as engineering, it is important that the cognitive load experienced throughout their education is managed appropriately in order to support the acquisition of necessary abilities and skills (Schmidt et al., 2007; Sweller, 1988), such as the cognitive abilities necessary for problem solving.

Problem solving plays a pivotal role in many engineering education frameworks as a result of its position in engineering (Hanney, Savin-Baden, 2013; Hmelo-Silver, 2004; Kirschner, Paas & Kirschner, 2009). As the desired attributes and skills of engineers are constantly evolving (Hisey, 2000; SEFI, 2016), it is difficult for educational frameworks and industrial training (continuing professional development [CPD]), to keep pace with the development of the exact skills required for certain tasks. The evolving nature of engineering skills and the likelihood of these skills to become obsolete is a major issue in engineering (LePine, Colquitt & Erez, 2000). Through the development of transversal skills such as problem solving and adaptability, education and industrial training programmes may develop a capacity to address and manage this issue (SEFI, 2016). Through analysis of the cognitive abilities required for problem solving, it is intended that the model presented in this paper may be used as a means of addressing this skills gap and support education and industrial training in keeping pace with the rapid advancements of technology and innovation and the skills deficiencies exposed through this advancement.

## **2. LITERATURE REVIEW**

### ***2.1. Problem solving in engineering education***

Problem solving has previously been outlined as one of the most important cognitive tasks in everyday and professional situations (Jonassen, 2000), particularly the engineering profession. Developing solutions to ill- and well-defined problems is a fundamental aspect of engineering (Jonassen, Strobel & Beng Lee, 2006) and a task that most engineers carry out daily, possibly multiple times daily. When problem solving, engineers are addressing a change that needs to be made, how the change may best be achieved, and the resources available to them (Koen, 2003). In consideration of this, it is clear that the problems faced between engineering disciplines may vary significantly. For instance, the changes that chemical engineers must address differ to those of a mechanical engineer (Koen, 2003), suggesting variances in the abilities they rely on to solve a problem. While the abilities to solve the problem may vary between engineering disciplines, problem solving is clearly a fundamental skill for engineers of all disciplines (Jonassen, Strobel & Beng Lee, 2006; Koen, 2003), emphasising the need to develop the proficient problem solving skills of engineering graduates.

Though differences have been highlighted between the educational frameworks implemented in engineering education, such as CDIO and PBL (Edström & Kolmos, 2012), one aspect that remains central to each of these frameworks is students' engagement in problem solving tasks (Crawley et al, 2011; Hanney & Savin-Baden, 2013; Savin-Baden, 2014) to support the development of problem solving abilities. There are many indicators of an effective problem solver such as the capacity to transfer reasoning from one problem to the next, and the ability to define the problem (Hmelo-Silver, 2004). In order for problem solving to be deemed effective, an individual must draw on different assumptions and skills depending on the type of problem they are solving (Schraw, Dunkle & Bendixen, 1995). As the context of problem solving in engineering and engineering

education is so variable,  $g$  may play a significant role in the development of solutions to engineering problems (Faber & Benson, 2017).

Contemporary engineering education frameworks provide experiences for students to engage in a range of tasks to support the development of abilities necessary to reason solutions and solve problems (Crawley et al, 2011; Hanney & Savin-Baden, 2013). At the early stages of engineering education students may experience more difficulty when problem solving as they have not acquired the necessary schema to solve the problem (Jonassen, 1997; Stieff, 2007; Sweller, 1988), regardless of engineering discipline. For instance, if a solution requires a deep technical engineering knowledge, a student may experience significant difficulty as they have not yet acquired the necessary knowledge to solve it, which remains true regardless of the discipline of engineering. This emphasises the importance of scaffolding students in developing the underlying abilities and schema for successful problem solving in engineering education.

Through the literature, cognitive structures have been presented and discussed as possible predictors of problem solving ability (Jonassen, 1997; Sweller, 1988). When taking a holistic view to the development of problem solving ability in engineering education, an exploration of an individual's cognitive abilities is necessary as problem solving is a higher-order cognitive task (Hambrick & Oswald, 2005). Before problem solving can be effectively examined in this way, an analysis of cognitive abilities must take place to support an understanding of the relationship between these elements.

## 2.2. Cognitive abilities

As earlier outlined,  $g$  is the difference in individual's capacity to learn (Kanfer & Ackerman, 1989). General cognitive ability is represented as  $g$  through the work of Spearman (1904), and continues to be recognised through contemporary research (Conway, Kane & Engle, 2003; Deary et al, 2007). There are a number of studies which explore general cognitive abilities such as Cattell and Horn (1967) who developed the concepts of fluid and crystallised intelligence, while Carroll (1993) investigated the principia of human cognitive abilities. The most contemporary and comprehensive model of cognitive abilities brings together these two theories to present the Cattell-Horn-Carroll (CHC) model (Schneider & McGrew, 2012). Throughout the literature, it is often empirically presented that cognitive abilities are hierarchically organised, with  $g$  positioned at the top of this hierarchy (Lubinski, 2004). The CHC model proposes that this hierarchy could be presented through a three stratum model; stratum III -  $g$ , stratum II - broad abilities, and stratum I - narrow abilities, as illustrated in Figure 1, with each contributing to the structure of the next. Narrow abilities are a number of fine elements that contribute to the make-up of a broad ability. For example, quantitative knowledge ( $Gq$ ) consists of mathematical knowledge (KM) and mathematical achievement (A3), while short-term memory ( $Gsm$ ) consists of memory span (MS) and working memory capacity (MW) (Schneider & McGrew, 2012).

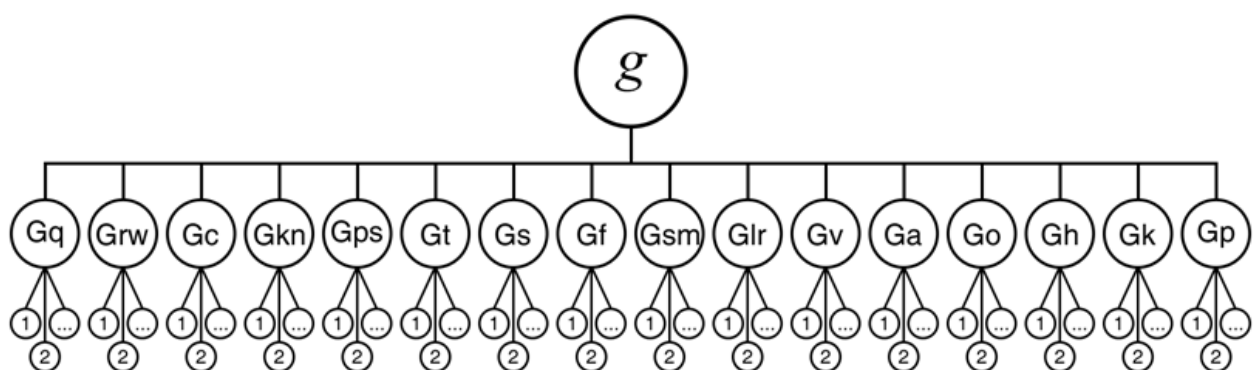


Figure 1. The Cattell-Horn-Carroll (CHC) model of intelligence (Schneider & McGrew, 2012).

Cognitive abilities are further categorised through acquired knowledge, cognitive speed, domain-free general capacities, and sensory- and motor-linked abilities (Schneider & McGrew, 2012). Stratum II, broad abilities, is the focus of this paper as through identifying the broad cognitive abilities engaged when problem solving, the narrow cognitive abilities are, simultaneously identified. Table 1, below, outlines the broad cognitive abilities presented through the CHC model (McGrew, 2009; Schneider & McGrew, 2012).

*Table 1 Broad Cognitive Abilities as presented through CHC model.*

Broad cognitive abilities	
Fluid reasoning (Gf)	Auditory processing (Ga)
Short-term memory (Gsm)	Psychomotor speed (Gps)
Long-term storage and retrieval (Glr)	Domain-specific knowledge (Gkn)
Processing speed (Gs)	Quantitative knowledge (Gq)
Reaction and decision speed (Gt)	Olfactory abilities (Go)
Comprehension knowledge (Gc)	Tactile abilities (Gh)
Reading and writing (Grw)	Kinesthetic abilities (Gk)
Visual processing (Gv)	Psychomotor abilities (Gp)

The necessity of each of these abilities to complete a task are dependent on the task requirements. For example, should an individual intend to solve a novel problem, fluid reasoning (Gf) may be more beneficial to utilise (as it is not dependent on any past knowledge and describes the ability to reason in novel situations), in comparison to domain-specific knowledge (Gkn) (as it is specified knowledge) as this knowledge may be unrelated to the problem itself. Likewise, if cognitive abilities are viewed in terms of their necessity for a particular profession, a chef would use their sense of smell (Go) and touch (Gh) frequently, whereas comparatively an engineer may rely more on their fluid intelligence (Gf) and domain-specific knowledge (Gkn). Therefore, the hierarchy of cognitive abilities for problem solving could vary significantly between professions and between disciplines, and within each of these professions e.g. between mechanical and software engineering and within disciplines (due to the variability of task contexts). Consequently, it becomes apparent that specific educational training is required to place a greater emphasis on certain cognitive abilities depending on the predominant skills of the profession in question.

Through analysis of these abilities (Carroll, 1993; Lubinski, 2004; McGrew, 2009; Schneider & McGrew, 2012), it can be seen that cognitive ability is a complex phenomenon. In addition to identifying important cognitive abilities which should be considered within education from the perspective of cognitive development, the relationship of these abilities to learning must also be considered. Depending on an individual's capacity relative to cognitive abilities, cognitive load may be experienced which may affect their capacity to learn (Sweller, 1988). In considering the complexity of cognitive abilities and information processing in the context of education, educationalists must reflect on cognitive load. This creates the need for teachers to acknowledge a balancing act. When the goal is learning (i.e. to invoke a change in students long-term memory through the acquisition of knowledge), cognitive load needs to be managed. The experience of cognitive load may be dependant in part on the level of capacity a student has in relative cognitive abilities. An intuitive response to this is that if cognitive abilities can be developed, there is an increased capacity for students to learn. However, the experience and effect of high levels of cognitive load may present the same impediment on the development of cognitive abilities. As such, in order to support student learning as much as possible from a cognitive perspective, the relationship between cognitive load and cognitive abilities needs to be explored. Such exploration can only be considered within the relativist context of education, and therefore there is a need to clearly frame the discipline which in this case is engineering or engineering education relative to the nature of learning tasks. The following is a preliminary attempt to create a framework that is useful for this purpose.

### **3. MODEL OF PROBLEM CATEGORISATION FOR ENGINEERING PROBLEM SOLVING**

When learning in engineering is considered, one often thinks of the technical knowledge associated with the profession. However, the technical knowledge required for one field of engineering will be significantly different to that of another. For example, the technical knowledge required for mechanical engineering will differ greatly to the knowledge required for software engineering. While different knowledge bases are necessary, problem solving is a fundamental element common to all engineering fields, however, the types of problems they have to solve are significantly different. Jonassen (1997) outlined that problems are traditionally defined by the problem domain, type, processes needed to solve them, and the solution. Therefore, it is clear that the cognitive abilities necessary to solve different types of problems would consequently vary. This is an element that must be carefully considered in a model of the cognitive abilities required for engineering problem solving.

Each of the broad cognitive abilities outlined through the CHC model (Schneider & McGrew, 2012) are likely to be necessary for engineering problem solving. While one may debate the use of some of these abilities in engineering, such as olfactory abilities, they may be necessary depending on the context of the task or problem. For example, if a material is machined at an inappropriate speed, it may produce an odour which may alert the machine operator to an issue and allow for the problem to be rectified. While each of these cognitive abilities may be required in engineering problem solving at some point, it is not necessary for each of them to be used for every task, and they will likely be important to varying degrees within specific tasks.

The cognitive abilities necessary to solve a problem will largely depend on two factors: whether the problem is well- or ill-defined, or if it requires a reflective or active means of determining a solution (Jonassen, 2000, 1997; Simon, 1973). This is similar to the model of learning presented by Conole, et al (2004), whereby learning may vary through: experience to information, non-reflective to reflective, and individual to social. While learning experiences are presented as differing in these ways, the model presented in Figure 2 proposes the means through which problems vary in engineering in terms of structure. Considering the variances in problem structure presented through the model, we may begin to position the cognitive abilities necessary for problem solving. Through this model, problems can transition between each of the continuums depending on the context of the problem and the means necessary to solve it. Problems may be viewed in terms of:

- Abstract reflective problem solving
- Abstract active problem solving
- Concrete active problem solving
- Concrete reflective problem solving

Should problems be considered as existing in one of the four quadrants outlined above, the cognitive abilities necessary to solve them may be evaluated. Furthermore, if problem solving is viewed as a dynamic and evolutionary process, problems may begin as an abstract reflective problem and possibly fluctuate between any of the remaining three quadrants. For example, if an abstract problem is to be brought from conception into reality, it may begin as an abstract reflective problem and transition to a concrete active problem. Throughout solution development, the problem solver may transition between reflective to active on multiple occasions as they reason about the problem. Similarly, as they progress, some variables may transition to well-defined while others remain ill-defined. It is imperative that we acknowledge the dynamic nature through which problem solving occurs as it ultimately impacts the cognitive abilities necessary to solve the problem.

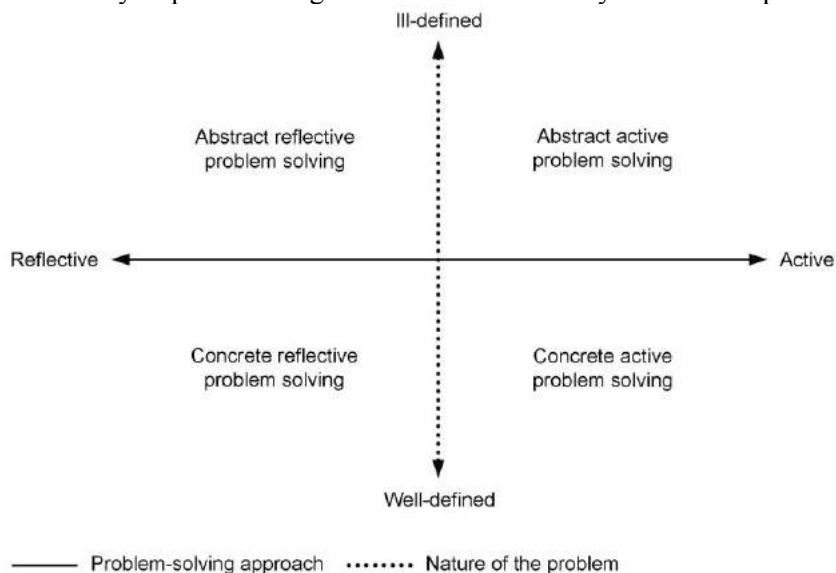


Figure 2. Proposed model for problem categorisation in engineering education.

Consider if an engineer was provided with an ill-defined problem brief and must develop and create a solution. The initial cognitive abilities to conceive a solution (abstract reflective problem), such as fluid reasoning (Gf) and comprehension knowledge (Gc), would vary significantly to those needed to bring the solution into reality (concrete active problem), such as kinaesthetic abilities (Gk) and psychomotor abilities (Gp).



Through viewing engineering problem solving in this way, we must also acknowledge that if an individual is presented with an ill-defined or open-ended problem, depending on their epistemic motivation, they may seize or freeze on a solution or approach (Kruglanski and Webster, 1996). Through doing this, the individual may turn the intended ill-defined problem to well-defined which may ultimately hinder the problem solving experience and cause variations in the perceived cognitive abilities necessary to solve the problem.

#### 4. DISCUSSION

The significance of problem solving in engineering must be recognised and supported through engineering education due to its distinctive role in the engineering profession (Jonassen, Strobel & Beng Lee, 2006). The problems faced by engineers of all disciplines vary greatly from well- to ill-defined problems and reflective to active means of reaching a solution (Jonassen, 2000, 1997; Simon, 1973). The dynamic nature of problem solving and the unique relationship between problem solving and cognitive functions (Anderson, 1980; Hambrick & Oswald, 2005) emphasises the need for curricular designers, educators and researchers to ensure that the relationship between cognitive functions and problem solving is thoroughly examined.

The model (Figure 2) presented in this paper proposes that engineering problem solving occurs between two continuums: well-defined to ill-defined, and reflective to active. This is not to say that a problem will remain in the realm that it initially begins in, it may move due to the transient nature of engineering problem solving, which would result in the cognitive abilities used to solve the problem transitioning also. This is a factor that we must be cognisant of in engineering teaching and learning approaches.

Perhaps the most important aspect of engineering education is supporting students in developing the capacity to utilise abilities effectively for problem solving. Therefore, it is important that we focus on supporting students in developing the underlying abilities necessary for effective and adaptive engineering problem solving. In doing this, the skills gaps that have emerged due to the advancements of technology and innovation (LePine, Colquitt & Erez, 2000) may be addressed.

The model presented aims to support researchers, educators and curriculum designers in identifying the cognitive abilities necessary to solve problems with consideration of the context that they are presented. It is presented as a theoretical means of classifying the cognitive abilities necessary for problem solving in engineering and encapsulates the dynamic and transient nature of engineering problem solving. It is envisioned that upon analysis and investigation of the model, it may support the development of curricula for engineering education with consideration of the abilities necessary for adaptive problem solvers so that the skills gaps emerging in engineering may be addressed.

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# Pupils' Goal Orientations in a Pedagogical Innovation Process: A Competition to Design and Manufacture Quick Hydrocopters

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To be able to learn innovation competencies, pupils need to have opportunities for problem solving in pedagogical innovation processes. Goal orientation has a motivational power for individual engagement in innovative activity. Goal orientation is understood as an individual disposition toward developing one's ability in achievement settings. It is a way to set goals for learning and working to achieve results. The aim of the study was to understand what the typical features of the most general goal orientations – learning, performance and avoidance orientation – were in a group of 5th and 6th grade comprehensive education pupils (N=19) within a case of hydrocopter design and manufacture competition as a pedagogical innovation process in craft, design and technology education (CDTE) -subject. The pupils were interviewed, and the qualitative data was analysed in a theory-driven content analysis. The results revealed that learning orientation was recognised as pupils' eagerness and enthusiastic commitment to the task of designing and manufacturing a quick hydrocopter. In performance orientation the commitment was neutral, and pupils managed the task while in avoidance orientation pupils had no interest to fulfil the task and did it with low efforts. However, with this data we do not know what factors were behind the learning orientations. The results cannot be generalized widely due to the nature of qualitative data and the size of the sample. However, the results help to understand how pupils with different goal orientations engage in learning tasks in CDTE. This is important information for teachers when they plan their teaching and proactively consider how to support pupils with various goal orientations in pedagogical innovation processes, even in competitions.

*Key Words: Goal orientation, Pedagogical innovation process, Competition, Motivation.*

## 1. INTRODUCTION

Goal orientation affects individual engagement in innovative activity. To be able to learn innovation competencies, pupils need to have opportunities for problem solving. Innovation competence is understood as a set of personal characteristics, knowledge, skills, abilities and attitudes that are connected in creating novelties in complex innovation processes (Hero, Lindfors & Taatila, 2017). Innovation competence can be learnt at school in practical design, making and manufacturing processes with open tasks (Lindfors & Hilmola, 2016) in so called pedagogical innovation processes, where goal orientation has an important role and effect on pupils' motivation on how they engage in their tasks. Goal orientation is understood as an individual disposition toward developing one's ability in achievement settings. It is a way to set goals for learning and working to achieve results. Individual learning orientations vary between learning situations. The most common goal orientations are learning, performance and avoidance orientations. (Delahajj & van Dam, 2016; Skalvik, 1999; Tapola, 2013; Pintrich, 2000.) The aim of the study is to understand what the typical features of the most general goal orientations – learning, performance and avoidance orientation – are in a group of 5th and 6th grade comprehensive education pupils (N=19) within a case of hydrocopter design and manufacture competition as a pedagogical innovation process in craft, design and technology education (CDTE) -subject.

For many years, a competition for design and manufacture of innovative hydrocopters in small size was organised in comprehensive education in Finland. A hydrocopter is a propeller-driven, engine powered

catamaran-type vehicle – a light one, used in circumstances where it is impossible to use any other vehicles. It goes on water, snow, ice and land. This competition, organised in co-operation with teachers and a private company, has two categories. One category is for beginners in 4th – 6th grades (10–13 years old pupils) with a pre-defined task to use certain engine, battery and propeller. The main material of the body of the hydrocopter (polystyrene) and maximum dimensions are regulated to keep costs low and competition fair. Otherwise pupils design their copters to get as high speed as possible in a water sink (Figure 1). The advanced category with more open task is for pupils in grades 5th – 9th (11–16 years old pupils). The three quickest hydrocopters can proceed to a next level and compete with other schools. (Hydrokopterikilpailu, 2013.) This research context is primary education in grades 5 and 6, category for beginners. In the figure 1 we can see how pupils’ designs vary in structure, size and appearance.



Figure 1. A hydrocopter prototype and the ones designed by pupils on 5<sup>th</sup> and 6<sup>th</sup> grade.

## 2. THEORETICAL BACKGROUND

### 2.1. Motivation in pedagogical innovation process

Intrinsic motivation guides learners to be active and to do things they are interested in. High intrinsic motivation enhances creativity and produces pleasure (Campbell & Jane, 2012.) This is the reason to activate pupils (Mensah & Atta, 2014) in CDTE and engage them into pedagogical innovation processes where they could use their creativity and develop, test and assess innovative solutions. A pupil with intrinsic motivation is usually learning oriented and works in CDTE by considering goals, being careful and persistent. This kind of pupil is not afraid of failure since he/she uses problem solving skills to design and fabricate a satisfying solution. As oppose to the intrinsic motivation, extrinsic motivation is based on influences outside of an individual, like rewards and punishments. Learning and making based on extrinsic motivation has an instrumental value. A competition as an example represents extrinsic motivator in a form of defeating and winning others.

To be able to engage pupils in learning, teachers should advance pupils’ motivation with different learning tasks and environments (Barak, 2010). The pedagogical innovation process is a creative and reflective problem-solving, design, manufacturing and testing process for developing new solutions into use in certain contexts. It involves ideation, planning, making, self-reflection and testing as well as assessment conducted either individually or in a group. (Lepistö & Lindfors, 2015; Lindfors & Hilmola 2016, Lindfors, Marjanen & Jaatinen 2016.) The innovative process develops contextual problem-solving skills and the critical optimisation of solutions in the material world (Lindfors, 2010). The process itself can serve as a contextual learning environment (Hero et. al., 2017) where a pupil can invent a solution to a challenge at hand. In the context of competition, the competition challenge can work as a motivating factor for a learning task since it gives opportunities for pupils’ own ideas, likes and living contexts even if competition is seen as an extrinsic motivation to win the others. Intrinsic or extrinsic motivation is behind the goal orientation during the process. A pupil with intrinsic motivation aims to develop him/herself and enjoys it. A pupil with extrinsic motivation behaves based on instrumental values. This pupil does not see possibilities to develop one’s own competence or enjoy learning new things. However, the meaning of instrumental value is not so simple (Cameron, 2001).

### 2.2. Learning, performance and avoidance orientations

Pupils’ goal orientations in learning are context and task specific (Tapola, 2013; Boekaerts, 2009) and can vary (Pintrich, 2000). In learning orientation, the learning task is a path to developing oneself and learning new

things which is rewarding in itself. Pupils usually choose challenging tasks and projects, work hard to reach the set goals and are open to critique. A difficult learning task is seen as a challenge to use one's own knowledge and skills to make the solution work. (Delahaij & van Dam, 2016; Pintrich, 2000.) E. g. if the solution of the artifact does not reach the aims, the pupil is motivated to work it further.

Typical for performance orientation is that by fulfilling a task a pupil can reach other rewards, like good grades, to get positive feed-back. These pupils usually choose easy tasks to be able to be ready as soon as possible, avoid mistakes and obstacles. Pupils can target good learning results but do not use their own problem solving skills to reach the goals. Instead of striving to get better results, pupils are satisfied with a lower level. They might not even try because of being afraid of failure as it could be seen as a sign of weakness. (Delahaij & van Dam, 2016; Mazler & Mueller, 2000; c.f. Pintrich, 2000.)

In avoidance orientation a pupil minimises efforts toward a learning task. The pupil is afraid of failure and tries to avoid situations in which there is a possibility of failure and social comparison. Proceeding with the task is not an opportunity but is rather more like a must. If a pupil faces obstacles he/she will compare him/herself to others and be frustrated. He/she can even give the task away. There is no persistence to proceed with the learning task. The passive way of working can be a shelter for the pupil. (Skalvik, 1999; Pintrich, 2002.) E. g. the pupil chooses materials and techniques that are familiar and not demanding.

### ***2.3. Competition as a part of a pedagogical innovation process***

Extrinsic motivation is seen to foster goal orientation in competitions through prizes and success (Ozturk & Debelak 2008). Prizes are considered problematic from high learning point of view. On the other hand, a competition can foster motivation and engage pupils in high level learning to meet the set goals. The competition that supports learning is seen as a process or a project in which pupils can invent and test whether their solutions meet the properties or goals (Caron, 2010; Sheridan & Williams 2011; Wittchen, Krimmel, Kohler & Hertel; Worm & Buch 2014) of the idea that is targeted in the pedagogical innovation process. There are yearly competitions in several countries to enhance science, technology, engineering and mathematics education (STEM), positive attitude to technology and career aspirations (Hendricks, Alemdar & Ogletree 2012; Robinson & Stewardson 2012; Welch & Huffman 2011).

## **3. RESEARCH DESIGN**

The research context was a comprehensive education in western Finland, the town school with 400 elementary education pupils. Altogether 19 were informants in the study. The group informants, pupils from 5<sup>th</sup> and 6<sup>th</sup> grade (N=9), were chosen on the basis that they were just starting their design and manufacture of a hydrocopter during spring 2015 in Craft, design and technology education (CDTE) subject. In Finland CDTE is obligatory for all pupils in grades 1 – 7 and optional in grades 8 – 9. Most often there are two weekly lesson hours for every pupil. Since it was important to follow the whole process of pupils, two of the researchers visited the school three times during the process. To better prepare pupils for the interview, a short questionnaire was used in the beginning and in the middle the researchers observed two classes. One of the purposes of the visits was also to get to know pupils and to build trust among them before the interview. The interview was contextual, which was seen to aid the interviewee give richer and more detailed data. The pupil had his/her own hydrocopter with him/her to be able to demonstrate the issues he/she was telling the interviewer. Taking part in the interview was voluntary. The school level competition was after the interview and pupils did not know how they would score in the competition. However, they had a possibility to test their hydrocopter in a water sink. Based on this try, they had some knowledge and experience of how their hydrocopter would perform in the upcoming competition.

Methodologically this is a qualitative case study. The target is to understand and explain the phenomenon instead of giving widely generalizable results. Especially, since competition is not explicitly part of the Finnish comprehensive education. The research question is: what the typical features of the most general goal orientations – learning, performance and avoidance orientation – are in a group of 5<sup>th</sup> and 6<sup>th</sup> graders within a case where competition is a part of a pedagogical innovation process in craft, design and technology education (CDTE) -subject. The interviews were recorded, anonymously transcribed by two researchers. The data was

analysed by theory-driven content analysis. After several readings it was categorized to three main categories: learning, performance and avoidance orientation (Table 1). The sub- and upper categories were formed by three researches.

## 4. RESULTS

### 4.1. Pupils' goal orientations in the pedagogical innovation process: design and manufacture of a hydrocopter

Based on the theory-driven content analysis, pupils' (N=19) goal orientation features typical for learning, performance and avoidance orientation in the pedagogical innovation process were recognised. The context was a competition to design and manufacture a quick and good looking hydrocopters. The result is presented in table 1 in relation to how different learning orientations vary according to learning task, innovation process, motivation, artefact and attitude to competition.

Table 1. Pupils' goal orientations in the pedagogical innovation process: design and manufacture of hydrocopter for competition in 5<sup>th</sup> and 6<sup>th</sup> grades.

	Learning orientation 26 % A pupil	Performance orientation 54 % A pupil	Avoidance orientation 20 % A pupil
Learning task	is motivated by competition task and learning experience	has a neutral attitude toward competition task	has no desire to engage in competition task
Innovation process	works well and has positive feelings about designing and making processes	works well during the process and does what must be done	cannot figure out the process or describe phases or details of it, hangs around
Motivation	works eagerly and is committed to the task	considers how to use the artifact	has no interest, has excuses for low performance
Artifact	pays attention to targeted properties	considers technical properties	does not pay attention – it does not matter
Attitude to competition	is motivated to achieve a good result	does not see good opportunities to score well	avoids competition

Half of the original phrases in the data (54 %) belonged to performance orientation category, one fourth (26 %) to learning orientation category and one fifth (20 %) to avoidance orientation category.

### 4.2. The learning orientation

The pupils with learning orientation had positive feelings toward the process of designing and manufacturing their hydrocopters. The pupils were engaged, enthusiastic, and also resilient during the process. They were able to stand some misfortunes and disappointments and still move forward with the process. At the same time, they felt tensed while they were figuring how they would succeed in the process.

*“I was enthusiastic. Finally, I had an opportunity to do something like this. I had waited for this at least a year.”* Boy, 8

The pupils pointed out their hydrocopters' appearance and performance capacity and by that they paid attention to the targeted properties of an artifact. Pupils had altered their plan during the process to get as good result as possible. They were interested in making details they felt were important either from the point of view of appearance or performance capacity.

*“Yes...I had a different kind of plan...but I altered it...I took one layer away to get better properties.”* Girl 6

*“Hmm... the propeller – I like the way I adjusted it on the top of the hydrocopter.”* Girl 9

Especially speed properties were carefully considered. Balance also, so the copter would go straight ahead to get as much speed as possible.

*"I considered the balance...so that the copter would not turn around while moving fast."* Girl 2

The phrases from the data in the learning orientation category consisted most typically positivity, orderliness, goal-direction, persistence and options and willingness to alter the plans if needed. The most obvious issue seemed to be that the new learning experience itself motivated learning-oriented pupils. It was obvious that the pupils with learning orientation were motivated at least to participate and even win the competition.

*"Yes, you have to win. You have to do your best!"* Boy 7

As a conclusion, the pupils with learning orientation had clear and high-level goals related to the product of the process. The competition was viewed as a motivating factor for own process, and pupils wanted to see how their hydrocopter would perform and how they themselves would succeed in the competition. Pupils were ready to struggle and solve problems in practice to fit the properties of a hydrocopter in an optimal way. By progressing with the properties and getting more speed was rewarding and raised positive feelings.

### **4.3. The performance orientation**

The pupils with performance orientation had neutral feelings toward the process of designing and manufacturing their hydrocopters. The main aim was to perform the task: to get the hydrocopter ready and finished. They were neutral or even under-evaluated the learning process.

*"Hmm... This is nothing special – just a normal school task."* Boy 1

*"First I thought this will be boring but actually I am satisfied with my hydrocopter."* Girl 4

The pupils chose easy solutions to get their artifact ready. The solutions were especially the ones they were familiar with. The original phrases in the data included often such words like little, almost, pretty sure or just ok.

Pupils considered the technical properties of the hydrocopter to fulfill the task, not to invent new solutions. If the manufacturing technique was not familiar for pupils, they easily felt it unpleasant or irritating.

*"...the sawing irritates me – I do not like the pieces..."* Boy 10

*"Sawing...it was a bit difficult."* Boy 12

Their attitude toward the process was neutral. The goals for the process were based on their likes, dislikes and skills. Way of working stayed at the same level during the process. At the time skills of the pupils, not the new ones, were the basis of their process.

*"Maybe it is a good one! I put it somewhere at home. Maybe I will use it."* Girl 2

*"I don't know. It is not so good – I mean the copter. It was not very easy. It was not difficult either... a middle type of task. I do not know what more to say."* Boy 16

*"I would have made my copter as it is with or without the competition."* Girl 14

As a conclusion, the pupils with performance orientation tried to fulfil the task to get their artefact ready with a reasonable amount of efforts. The competition was viewed as a positive factor, but pupils did not challenge themselves for it. The competition was not a guiding factor in their work. Pupils did not challenge themselves in practice to fit the properties of a hydrocopter in an optimal way. They saw the learning task as one of the other similar learning tasks and had a neutral attitude to their work: no big challenges, no big disappointments,

neutral feelings. Most of the pupils however had some ideas of where and how they would use their hydrocopter during summertime.

#### **4.4. The avoidance orientation**

The pupils with avoidance orientation were not interested in the design and manufacturing of their hydrocopters nor did they engage with the task. They had no interest in solving arising problems during the process or alter their own performance. They were not satisfied with their artifact either.

*“This goes in the wrong direction and does not go straight. There parts are in wrong corner. This piece is also aside...it should be more in the middle.”* Boy 19

*“I could have done a better one but anyway ...it is the same to me how it looks like.”* Boy 10

*“I don’t know. I don’t like competitions. I do not know if I like the hydrocopter or not.”* Boy 8

The pupils with avoidance orientation could not say explicitly what, how and why they did something or did not. They were not motivated or goal-oriented. They wanted to make everything as fast and easily as possible. Even if they were not satisfied with their artifact, they were not ready or prepared to make any corrections or alterations. The competition was not a supporting factor, but more or less the opposite.

## **5. DISCUSSION AND CONCLUSIONS**

This study was executed in everyday school context in 5<sup>th</sup> and 6<sup>th</sup> grade as a part of CDTE -subject in comprehensive education with 19 pupils as informants. The analysis was theory-driven. The data could have been gathered in any group that participated the hydrocopter competition. Based on the results it is possible to describe a typical pupil with achievement, performance or avoidance orientation in the context of a competition in CDTE. However, the results cannot be generalised widely due to the nature of qualitative data and the size of the sample.

The results revealed that learning orientation was recognised as pupils’ eager and enthusiastic commitment to the task of designing and manufacturing a quick hydrocopter. In the performance orientation the commitment was neutral, and pupils completed the task while in avoidance orientation pupils had no interest in fulfilling the task and did it with low efforts. However, with this data we do not know what factors are behind the learning orientations. E.g. teacher effect and social relations have been reported to have some meaning (Mensah & Atta, 2015). As a future research topic, this could explain the reasons behind e.g. avoidance orientation and it would probably be possible to find new ways to support pupils in finding interest and engage them into pedagogical innovation processes.

In the context of competition, the learning orientation pupils managed to engage into the pedagogical innovation process. The competition was an encouraging factor for them while it was the opposite for performance and avoidance orientation even though winning the competition as a reward refers to extrinsic motivation (cf. Delahajj & van Dam, 2016; Ozturk & Debelak 2008). However, it seems that winning or scoring well in the competition was too difficult a challenge for performance orientation pupils despite the fact it had been a reward for them. For learning orientation pupils, the competition was a challenge to develop their own competencies and design an innovative solution based on intrinsic motivation (Campbell & Jane, 2012; Cameron, 2001). For avoidance orientation pupils the competition task was a wrong task. They did not want to learn anything and were afraid of failure. With them the process was more about coping, not enjoying learning. On this basis, teachers should consider carefully pupils’ goal orientations to be able to recognise these and proactively support their processes. The pedagogical innovation process requires, on teacher’s part, pedagogical expertise to support motivation and recognise typical features of goal orientation as well as an ability to understand the principles of inventive activity and process. Since the goal orientation is task and context specific (Tapola, 2013; Boekaerts, 2009; Pintrich, 2000) individual tasks, support and tutoring could engage pupils in pedagogical innovation processes, even into competitions.



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# Developing a Learning Environment for Innovation Learning in Craft, Design and Technology Education

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Craft is a compulsory learning-by-doing subject for pupils in grades one to seven. The activities are based on craft expression, design and technology (CDT). This research is part of national endeavours to develop innovative CDT as a basic education subject. This paper briefly explores two studies in which technical work and textile work teachers taught together in a shared learning environment, rather than in traditionally separate learning environments divided into soft and hard materials. The aim is to develop criteria for a new kind of learning environment that promotes innovation learning in pedagogical innovation processes. A new kind of teaching culture that would advance pupils' innovation processes does not arise without deliberate new practice. The first study used a mixed methods approach, including systematic observation, inquiry and pair interviews of five co-teaching teams in primary school, to test the new teaching culture. The second study used an experience sampling method in the form of a mobile application to reveal various parts of pupils' design and making processes in the school setting. The present research offers two perspectives on how to advance pupils' innovation processes in a school context. Though this is action research, the results are consistent with earlier studies on school reforms and offers suggestions for how to face the CDT teaching tradition. Progress requires changes in both thinking and teaching culture—not only theoretically, but also in practice—to develop new ideas for how to renovate and construct learning environments that support pupils' innovation processes. The key finding is that collaborative teams can support teachers' and pupils' innovation learning activities when the work is supported by shared practices, spaces and new tools.

*Key Words: Learning environment, Basic education, Co-teaching, School reform, Pedagogical innovation process.*

## 1. INTRODUCTION

In Finland, craft teaching has a 150-year history in education for men and women and, later, for boys and girls. After the 1970s school reform, craft was divided into technical work and textile work in comprehensive schools. Since 1998, according to the Finnish Basic Education Act, crafts has been a single school subject. Thus, following a long and divided teaching tradition involving separate working spaces, teacher attitudes, ritualized routines and supporting myths, teaching has finally been reorganized into a co-teaching model. The change has been slow. In 2005 (Peltonen, 2007), the search began for new ways to educate teachers in a manner that would reduce the traditional division. In-service teachers still operate according to this traditional division.

As a school subject, craft is similar to design and technology education or technology education in many countries (Lepistö & Lindfors, 2015; Lindfors, 2015). In this paper, the concept of craft, design and technology education (CDT) is used as an English translation representing the tasks and objectives of Finnish craft education. Craft involves human- and practice-based experiential work with problems and challenges to create usable solutions. Design involves creativity and problem-solving based on values. Thus, design is part of a holistic craft (used in the Nordic context) or pedagogical innovation process. Technology involves understanding and using technology as a method, tool or technique to design, manufacture and fabricate innovative solutions on a student level, supporting technological literacy.

The present paper, which is part of an article-based dissertation, offers perspectives on creating new learning environments in CDT education based on two peer-reviewed pilot studies conducted in Finnish comprehensive education (Jaatinen & Lindfors, 2016; Jaatinen, Ketamo, & Lindfors, 2017). In the Finnish context, prior to 2014, two gender-based options for CDT existed. According to the National Core Curriculum (FNBE, 2014) and the Committee on the Alleviation of Segregation (FNAE, 2016), this approach is no longer permitted.

However, in many schools, craft education is still divided into textile and technical work periods in two mentally and spatially separated learning environments. Pupils study a wide range of materials, but their different interests are not emphasized in contemporary ways. Prior research on what pupils choose to study when given a choice between textile work and technical work (with no other options) has shown that pupils tend to choose traditionally: girls choose textile work and boys choose technical work (Lepistö & Lindfors, 2015; Lindfors, 2012b).

In the present paper, we introduce the KÄSITÄKSÄÄ learning environment development project for CDT education (Jaatinen, 2017). Through two different studies, we examine two perspectives affecting the development of the learning environment: the teacher perspective, which shows how to create a new pedagogical approach based on co-teaching, and the pupil perspective, which shows how to develop teaching facilities and assessment methods. In an experimentation-driven approach, the information needed to realize critical phases does not yet exist and must be created by testing what works and what does not and learning from these experiences (Hassi & Tuulenmäki, 2012). An innovative idea in this research context is to first alter the pedagogical approach, thereby increasing the didactical possibilities supported by new spatial and instrumental resources, and to then make recommendations for developing learning environments based on observations of the studies. As Sawyer (2008) suggests, the basis of innovation is multidisciplinary collaboration.

## **2. THE THEORETICAL POINT OF DEPARTURE**

### ***2.1. Finnish school reform in basic education and the context school***

The national core curriculum has been revised five times since the establishment of the comprehensive school in 1970. Finland has very few private schools, and learning outcomes do not vary significantly among schools. A common aim in CDT education is to make such education compulsory and shared for grades 1 through 7. However, a suitable solution for CDT education has not yet been found. According to recent research on attitudes towards CDT, pupils participating in education emphasizing technical work have distinctly more positive attitudes than pupils participating in education with equal amounts of technical and textile work. Pupils participating in education emphasizing technical work are also more likely to take part in an optional CDT course (grades 8 through 9) than pupils participating in education with equal amounts of traditional division (Hilmola & Autio, 2017).

Design and technology education can develop students' skills in a variety of equitable ways (Niiranen, 2018). For example, CDT education can be carried out according to the following models: 1) shared craft education, 2) from technology to design, 3) from idea to product and 4) innovation processes (Lindfors, Marjanen, & Jaatinen, 2016; Lindfors & Hilmola, 2016). In principle, gender is not a key issue when organizing teaching, and teaching is not based on sex; rather, we are actively building gender always (Lorber, 1994). Both boys and girls face various kinds of problems, and pupils must be understood as a heterogenic category (Lunabba, 2013). Equality is not about using 50% hard and 50% soft materials or providing everything to everybody through an equal division of production technologies. Instead, more alternatives must be tested.

Beginning in 2006, a wide range of technologies were implemented with equal amounts of technical and textile work in the project school. Co-teaching was launched in autumn of 2014 as a new solution for implementing the ideas of the new curriculum (FNBE). CDT was defined as a design process involving several techniques. This way of organizing CDT to emphasize pupils' varying interests and shared activities in a single learning environment has not previously been studied.

### ***2.2. Learning environment and design process***

The design of CDT learning environments has not yet been studied in Finland. Examples from Sweden show us that separate workshops have different classifications according to masculinity (Sigurdson, 2014). We are facing a major change toward teaching CDT in an equitable learning environment. In an altered learning environment, a CDT workspace consists of an individual workplace for each pupil, special workshops involving the use of various materials and technologies and a place for co-design and co-working. While working, pupils use the CDT workspace in a meaningful way by moving between their workplaces and the

workshops both independently and according to the teacher's guidance. This is done in the manner required by innovation learning and the phases of the pedagogical innovation process. The pedagogical innovation process is a creative and reflective problem-solving and design process for developing design thinking. It involves ideation, planning, making, and self-reflection conducted either individually or in a group. Learning environments offer pupils opportunities to design, manufacture and fabricate innovative solutions to meaningful problems or challenges; to assess holistic processes; and to develop highly usable solutions (Curedale, 2013; FNBE, 2014; Lepistö & Lindfors, 2015; Lindfors, 2012a; Lindfors & Hilmola, 2016; Lindfors et al., 2016).

In the project school, several aspects of the learning environment (Manninen et al., 2007, p. 15) were modified to support innovation learning (Figure 1). First, the space for learning was organized to enable co-teaching, and later, it was decorated as a lounge instead of a factory. Second, the pupils' workplace and different workstations and workshops were supported according to different phases of the flow. For example, what was previously the supervisor's booth was transformed into the pupils' secret corner or ideation place. Third, the practice was developed to be more design-oriented, focusing on transversal competence and co-teaching. Fourth, the community was widened spatially and virtually to support natural connections to other subjects. Finally, following Wilson's (1996, p. 3), changes were made to the learning environment resources, such as the QR code instrument used in the second study (Jaatinen et al., 2017).



Figure 1. Modified CDT learning environment

Earlier studies give us a broad perspective of good learning environments. Well-being in schools is based on school conditions, social relationships, means for self-fulfillment and health (Konu & Rimpelä, 2002). Learning environments should be safe and reflect connections to surrounding society (Piispanen, 2008). Good learning environments also depend on teachers' active collaboration in the design process (Nuikkinen, 2009). Successful teacher communities require supportive leadership, group dynamics and composition, as well as trust and respect for professional development (Vangrieken, Meredith, Packer, & Kyndt, 2017). Finally, learning environments should support possibilities to use modern teaching and learning processes (Kuuskorpi, 2014, 2012).

### **2.3. Co-teaching and new information technology resources**

Craft learning environments play a key role in bridging the humanities and the sciences (de Melo-Martín, 2010; Snow, 1964). Traditionally, textile work is considered more human- and aesthetically oriented, while technical work is considered more technical (i.e. based more on natural sciences) (Kojonkoski-Rännäli, 2001, 2006). Recently, the co-operation between these two sciences has increased, and innovative campus complexes have been developed to bring together different experts. The project school's floor plan solutions focus on equality and individual needs (Nuikkinen, 2009; Sigurdson, 2014). Pupils need transversal competencies in their living environments that are both aesthetic and technical. The traditional system of allowing pupils to choose part of the content of their CDT led pupils toward unequal positions in both evaluation (Hilmola & Syrjäläinen, 2014) and technology learning (Lindfors, 2007). Co-teaching is a teaching experience for a heterogeneous group of students organized by two or more teachers, typically teaching in the same space, involving active teacher participation in planning, instructing and evaluating (Cook & Friend, 1995; Murawski & Lochner, 2011).

It is possible to design a new kind of CDT learning environment in the workspace using special workshops (Lindfors, 2010). Pupils' experimental production projects should be encouraged (Kallio, 2014). Earlier international studies have addressed the same questions, showing that it is possible to deconstruct technology's masculinity (Dakers, Dow, & McNamee, 2009) and that aesthetic awareness has creative value in design

education (Baynes & Baynes, 2010). An obstacle to development is the current lack of philosophical discussions of technological knowledge among CDT teachers (Hilmola, 2009; Norström, 2014). Teaching in technology has developed from isolation to co-operation (Männikkö-Barbutiu, 2011). Joint practice development is key to self-improvement (Hargreaves, 2014) and self-regulation is an important topic when defining learning tasks related to pupils' own technological and functional experiences (Metsärinne, Kallio, & Virta, 2015). In addition to social and physical considerations, information and communication technology is an important aspect of contemporary learning environments. Pupils' activities can be studied and supported in real time using mobile applications (Ketamo, 2009, 2011).

### 3. RESEARCH METHODOLOGY

Changes must be initiated and nurtured by real, identifiable people, including both individuals and groups (Engeström & Sannino, 2010). Teacher collaboration is key when experimenting with new ideas (Vangrieken, Dochy, Raes, & Kyndt, 2015) and attempting to implement a national core curriculum. To consider different perspectives on developing the learning environment, two studies were conducted. The research questions addressed in these studies were: I What is craft teaching when the approach is based on co-teaching instead of division? II How are pupils' activities and progressions seen at a curriculum level when using information collected by a self-assessment application in teacher-defined activities? The findings of this paper are based on two studies and represent possible means of enhancing practice (Figure 2). Thus I + II = How can teachers' and pupils' activities be supported in innovation learning?

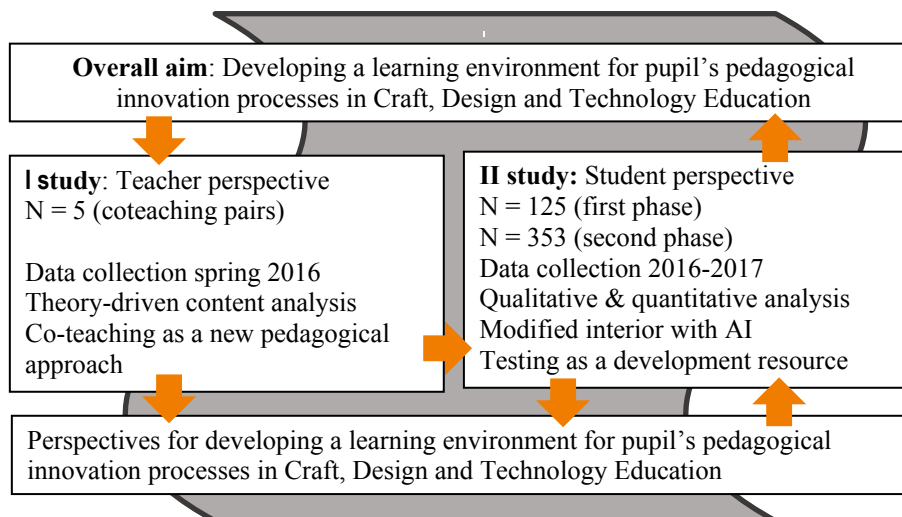


Figure 2. Research design

The first study used a mixed methods approach involving systematic observation, inquiry and pair interviews of five co-teaching teams in primary school. In the second study, an experience sampling method was used to examine a pilot implementation of a mobile application designed for use in classroom settings based on analyses of co-teaching. There was a need for a method to reveal pupils' activities supporting and not supporting pedagogical innovation processes. Using these methods, new scientific information was collected and used to develop principles for a future-oriented learning environment experiment.

### 4. RESULTS: STUDIES I AND II

Study I (Jaatinen & Lindfors, 2016) analysed co-teaching teams (two teachers, a classroom assistant and 18 to 21 pupils) in a learning environment that had been redesigned to promote pupils' pedagogical innovation processes. Qualitative data were drawn from systematic observations (22 hrs, 2 to 6 hrs/team), inquiries and pair interviews of five co-teaching teams in primary school grades 3 through 6 (Figure 3). Based on the theory-driven content analysis, the results of the study revealed that co-teaching was positively adopted as a new teaching approach. However, not all possibilities were utilized. For example, pupils' work should have been developed in a more collaborative direction. The initial findings suggest that proficiently performed co-teaching (Murawski & Lochner, 2011, 2014) opens new didactic opportunities to develop pupils' innovation processes.

The results are presented by describing 11 core CDT co-teaching competencies and ways to master both emerging and developing coteaching and proficient coteaching.

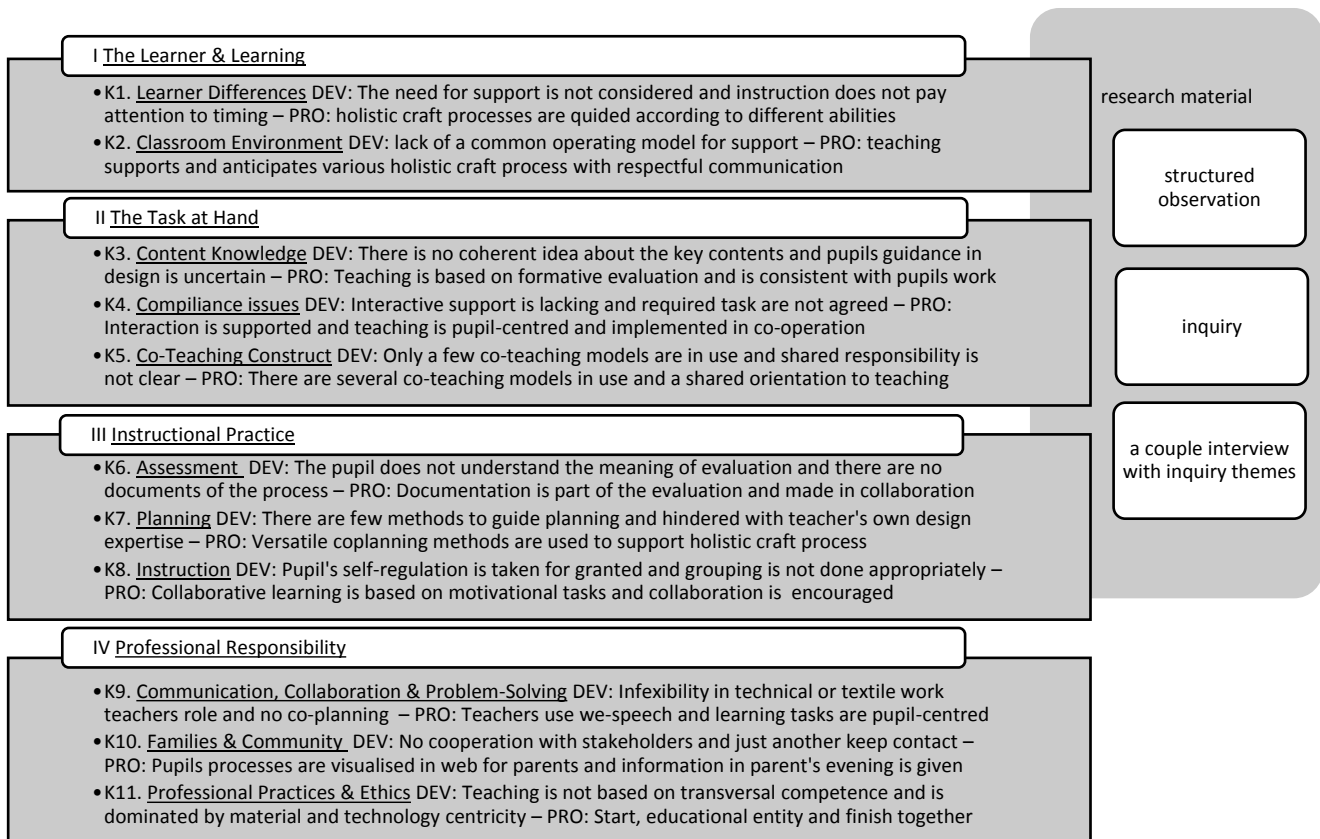


Figure 3. Researching and developing the core competences of CDT co-teaching: competences for K1 through K11. Created and adjusted based on the work of Murawski and Lochner (2011, 2014). Content based on the work of Jaatinen and Lindfors (2016). DEV = emerging and developing co-teaching; PRO = proficient coteaching.

Study II (Jaatinen et al., 2017) investigated pupils' processes in CDT education using an instrument for data collection and self-assessment. The school architecture and web-based learning environment were combined. The aims of the study were to: 1) make pupils' CDT processes visible in everyday classroom practices through information collected by a mobile application and 2) identify the curriculum topics covered during everyday classroom practices. The data were collected using an experience sampling method (Csikszentmihalyi, 2014; Hektner, Schmidt, & Csikszentmihalyi, 2007) with a gamified learning analytics instrument. The teachers' classroom activities served as the backbone for the thematic mapping of the curriculum (Figure 4). Preliminary measurements were carried out in grades 5 through 6 of a Finnish primary school (ages 10 through 12, n = 125) during a four-week period in 2016. The list of classroom activities was updated and tested in 2017 with all the pupils in the project school (N = 353). The key findings were: a) the self-assessment was easy for the pupils as a technical process, but there were several factors in the everyday classroom setting that made the process challenging, and b) it was relatively difficult for teachers to describe the classroom activities and process topics in terms of the curriculum. However, following the preliminary test, the teachers described activities in more detail and developed new activities that better supported the ideas of the curriculum.

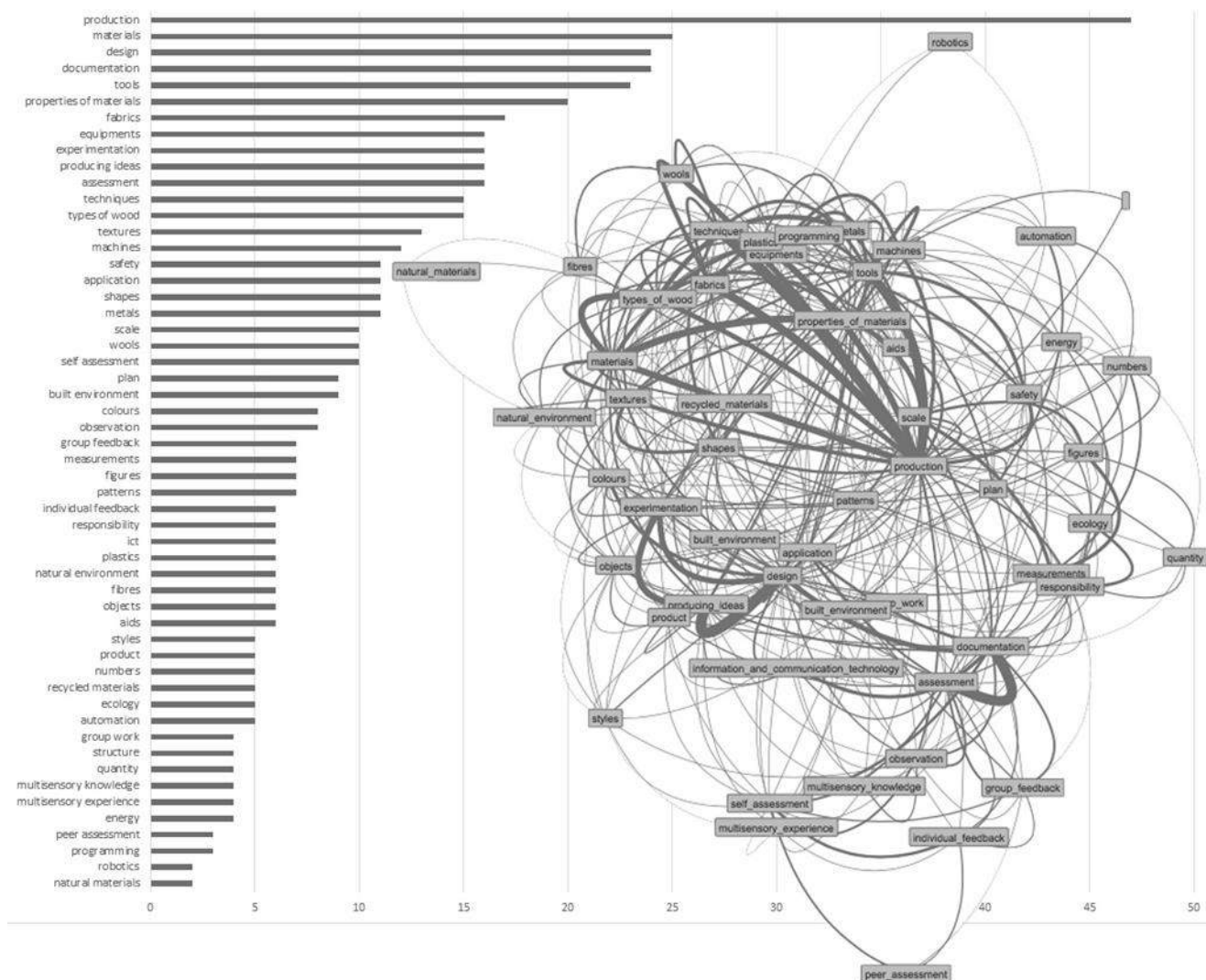


Figure 4. Left: the frequencies of the 54 curriculum keywords in the system. Right: a semantic network, built according to the keywords of the activities defined by teachers.

aken together, the results of the studies I and II facilitate a consideration of the CDT learning environment from different perspectives (Table 1). The results indicate that co-teaching teams can support teachers' and pupils' innovation learning activities when their work is supported by shared practices, spaces and new tools. Using the mobile application developed for the learning environment, teachers still initially defined craft as either soft or hard material production, but also improved their coverage of the content of the pedagogical innovation process. From the teacher perspective, it is important to support a shared vision of CDT and to use tools that face traditional approaches. From the pupil perspective, the key issue is not achieving equality across different materials but getting intensified support for self-regulation and individual needs in various processes. The learning environment should primarily be a space and a mental state for cultivating design and innovation, instead of mere production.

Table 1. Overview of the content analysis conducted in studies I and II.

Original publication	Study I	Study II
Data	Systematic observation, inquiry and pair interviews	Teacher-defined activity sets and detailed log data on pupils' processes
Method	Triangulation	Experience sampling method
Unit of analysis	Co-teaching core competence	Content objects and semantic networks of pedagogical innovation process
Focus of analysis	Teacher perspective: Possibilities of co-teaching	Pupil perspective: Pupils' holistic CDT processes in everyday classroom practices

Original publication	Study I	Study II
Intervention	New pedagogical approach	Piloting the ESM tool
Specific aims	Explore social and pedagogical factors in co-teaching	Explore mental and physical factors in pupils' processes
Results	Co-teaching is possible in CDT Competencies are mastered from emerging and developing to proficient coteaching and can be developed with pedagogical support	Pupils' activities are based on the options offered by teachers The piloted tool helped teachers better describe activities that supported the pedagogical innovation process
Answering overall research questions: Exploring different perspectives on change processes	Proficiently performed co-teaching opens new didactic opportunities to develop pedagogical innovation processes	Visualizations make pupils' different processes visible Classroom practices are not balanced in relation to objectives
Use of multiple materials	Learning tasks, co-teaching approaches	Pupils' different interests and shared activities
Innovativeness	New didactic opportunities	Help of new ICT tools
Equality	Intensified, gender-independent support according to pupils' needs	Key conceptual equality in CDT
Main contribution	Support for pupils' needs vs. teachers' needs	Better use of ICT can support the holistic craft process

## 5. DISCUSSION / CONCLUSIONS

Based on the results, it is a paradox that CDT teachers both oversee innovation learning and advance it through their work. In other words, CDT teachers are the owners of innovation learning in schools (Lindfors, 2012a).

Perspectives on developing a learning environment for pupils' pedagogical CDT innovation processes:

- 1) **The teacher perspective:** A good CDT learning environment consists of teachers' appropriate division of labour, as well as an environment and tools that support pedagogical innovation processes and pupils' self-assessment. One possibility is co- or team-teaching. Teaching design is challenging, even though teaching has always followed the objectives of CDT. In the teaching culture, everything affects everything. In this study, we focused on a single classroom; however, it is important to remember that technology education exists also outside of CDT.
- 2) **The pupil perspective:** For a CDT teacher, it is surprising that the only tool related to learning environment objectives described in the core curriculum (FNBE, 2014) is a mobile device. For pupils, it is an easy tool to use. Curriculum keywords might appear in different frequencies if design thinking and technological literacy are understood as main concepts of CDT. Timely support for pupils' needs is more important than the provision of multiple materials. It is important that pupils be able to choose the workshops and technologies most suitable for specific solutions. However, pupils need guidance in both design and the technologies used in production.
- 3) **The CDT:** The learning environment transcends the physical place of the classroom. The future-oriented CDT learning environment can be seen primarily as a "state of mind". It involves the re-evaluation of both teachers' and pupils' current practices. If workshops are not connected to the workspace in a way that makes them easily accessible to pupils, the old division in the curriculum will re-emerge.

The product- and gender-based traditions that have developed over the past 100 years are deeply entrenched. For some teachers and pupils, these traditions are so self-evident that they are difficult to question. Prior work has increased our understanding of innovation learning in CDT and revealed certain "truths" behind this concept. Though the present study presents action research conducted in the first author's school, the results are consistent with earlier research on school reforms. Attempts to change instructional practices take time and often fail (Hargreaves, Lieberman, Fullan, & Hopkins, 2009; Cuban, 1984; Fullan, 2011). This study offers suggestions for how to address the CDT teaching tradition. Earlier research on school reforms can be used, but



an optimal distribution system has not yet been developed. Teachers are not researchers, and reform should start from the bottom and move upward (Hargreaves, 2014). For this reason, new approaches are now being tested in real classroom settings with real teachers.

The old teaching system can be complemented or replaced, but we devote more attention to guiding in-service teachers in developing a manifold CDT learning environment. We must focus on the subject content and understand that innovation cannot be the work of a single person. In moving from the teachers' perspective towards the pupils' perspective, we see that the learning environment fosters learning in the surrounding society. With a little help from ICT and physical changes, a social learning environment can be developed. To accomplish such changes, however, teachers must work together. This is where CDT education is the most useful. Developing a new kind of CDT learning environment requires changing our thinking and considering the whole—not just theoretically, but also in practice—to find new ideas that will work. Ultimately, collectively held values make schools innovative.

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# Teachers' Views on Training Spatial Skills and Creative Thinking by Using Model Construction: A Case Study from South Korea and Sweden

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In order to educate the best engineers for future challenges, capabilities such as creativity and spatial skills are regarded as two key competences. The obvious importance of training for these capabilities has been debated by school authorities, as well as by industry. School's steering documents, however, are not clear on how and when those capabilities should/could be taught. The use of different teaching materials permitting students to build and design three-dimensional models is one way of training and practicing these capabilities in school. In this study, we explore how, when and why teachers in South Korea and Sweden are relating construction and design of three-dimensional models with the teaching of creativity and spatial skills. The main focus is laid on studying possible similarities and differences regarding: 1) educators' teaching aims and approaches when using building and modelling tools in their teaching, and 2) their view on the necessity of learning capabilities as creativity and spatial skills. Seven teachers in each country represent different grade levels in the educational system; from preschool up to high school. All teachers had used 4DFrame as a pedagogical tool in their teaching. The fourteen informants were interviewed according to a semi-structured approach. The interviews were thereafter transcribed and analysed and compared after a valuation of the answers on a Likert scale performed by the authors. The preliminary results show that teachers in the two countries agree on the importance of training the capabilities spatial skills and creativity although none of the countries investigated has a well-functioning system where those key-competences are trained at all schools/levels.

*Key Words: Spatial skills, Creativity, Hands-on activities.*

## 1. INTRODUCTION

The authors of this paper all have long experience working with model construction and hands-on experiments for students. Their ultimate goal has always been to increase interest for and knowledge about science and technology among youth in order to get a more technology-astute general population.

The reason for choosing model construction as a tool for this purpose is our belief-backed by evidence (Westergren et.al., 2010; Manninen Hedkvist, 2010)-that the opportunity and experience of physically building three-dimensional models, combined with the ability of solving a task, promotes creativity and problem solving skills. It is also shown that building with LEGO may increase students' performance in mathematics (Hussain et.al., 2006), which is linked to students' spatial ability. In turn these are capabilities strongly connected to interest and self-confidence (<http://www.vetenskaphalsa.se/sjalvkansla-och-kreativitet-i-skolan>), (Adolfsson, 2011).

In order to train the best engineers for future challenges, capabilities such as creativity and spatial visualization are regarded as key competencies. A number of studies (Margo, 2009; Lubinsky, 2010;) point out the importance of having the capacity for spatial visualization and creativity (Hoidn & Kärkkäinen, 2014; Cachia & Ferrari, 2010). in order to manage higher levels in math, science and technology. Industry, as of late, is also

arguing that these skills should be taught in schools (Spinks et.al., 2006) so as to give students the best preconditions for a successful career in future society.

Supportively, studies have shown that increasing students' creativity and spatial skills also increases their self-confidence when working with math, science and technology. This, in turn, is a good predictor for successful study performance in those subjects. This provides an additional reason for using model construction in education.

The importance of teaching these skills has been debated internationally by school authorities at municipal and national levels. Such topics have been in their curricula at various times. Whether or not training in these capabilities should be a mandatory part of the school programs (Skolverket, 2015) is still often under discussion.

In this study, we have elected to compare South Korea and Sweden: two countries that have handled this topic quite differently. It shows how teachers from different classroom levels use construction of models as a tool for training spatial skills and creativity. The main focus is on studying possible similarities and differences regarding: 1) teachers' subject content competencies and teaching approaches, 2) support from authorities and policy documents and 3) conditions for teaching students. Our overall research question reads:

*In what ways (and contexts) do teachers in South Korea and Sweden relate the use of three-dimensional models to the development of students' creativity and spatial visualization?*

Teachers in both countries who had taught using the educational tool 4DFrame were interviewed. This will most probably give biased results, as these teachers are expected to be more engaged than regular ones. But, being engaged, they may also best describe their experiences with modelling activities.

## **2. BACKGROUND**

### ***2.1. The importance of teaching creativity and spatial skills***

Being creative and entrepreneurial are abilities currently considered to be very important for living in modern society. With Industrial Revolution 4.0, future engineers are expected to be more flexible, and the ability to create your own working opportunities is seen to be much more important than today. This on-going change is expected to provide fewer large companies handling the entire national technical competence over decades, with smaller consulting companies being key players in technical development. Some studies mention that more than 85% of today's students will have occupations that have not even been invented yet (Institute for the Future for Dell Technologies, 2017).

Already in the 1960's it was identified that spatial visualization was an important skill to have for a variety of professions in the engineering and Science areas (Veurnik & Sorby, 2011). It is shown that high ability in spatial thinking is one of the best predictors for managing a higher degree in science and engineering. Other studies show that perception is as important as the cogitative ability for being creative and innovative. Previous surveys show that spatial skills are a must in order to be able to use today's digital tools and computerized models of products (Gilbert & Boulter, 2012) If this ability has such a strong relation to study results in science and engineering, it is important for all countries that are interested in a technically-literate population to teach this to today's students.

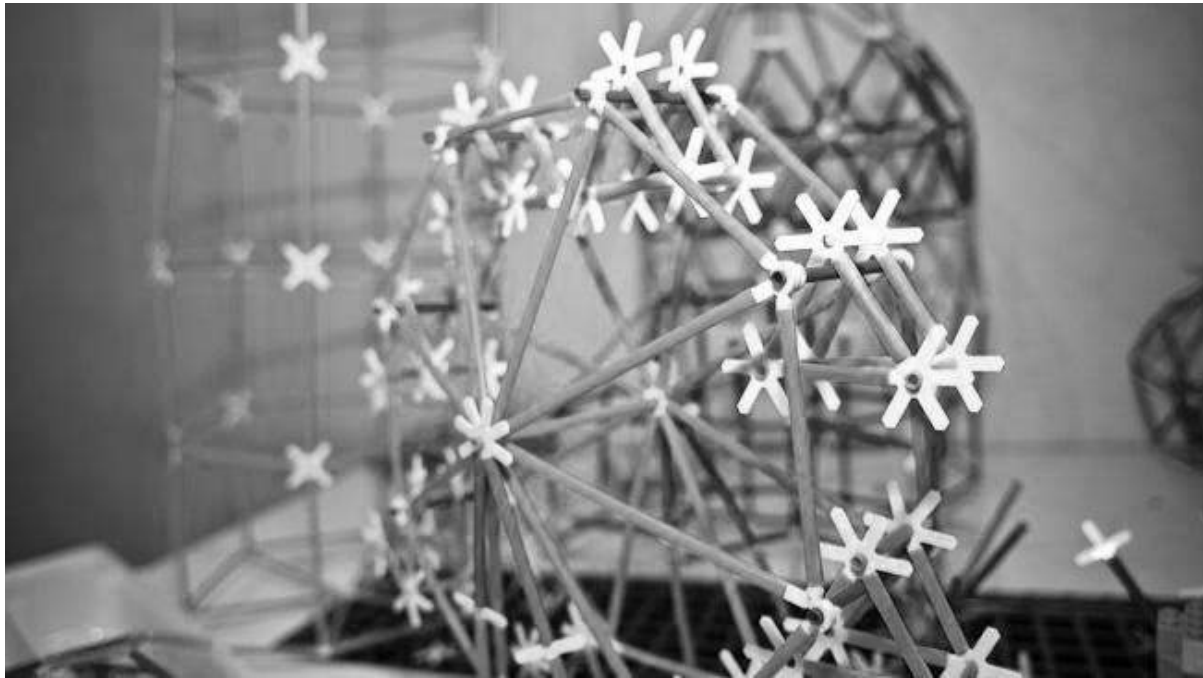
### ***2.2. How can creativity and spatial skills be taught?***

Different studies have shown that activities that require eye-to-hand coordination are those that help to develop these skills (Sorby 2009). Hands-on work, such as painting and drawing are other methods that improve spatial thinking. It has quite recently been shown that even though spatial skills is something that is developed over time it can be trained fairly easy and it has been shown that it is possible to increase engineering students spatial ability i.e. for improving their results in engineering or math in order to increase the retention at university level (Sorby, 2009; Verurink & Sorby, 2011). Another example for how to train creativity is the

interactive exhibition, Discover the Art, where pupils are allowed to build mathematical structures (Thuneberg et al., 2017).

### **2.3. 4DFrame educational tool**

In this survey, teachers who used to work with an educational tool called 4DFrame are the informants (Park, 2006; 2015). All worked with building models in their teaching. 4DFrame uses plastic tubes and various connectors. It is very flexible, and can be used for different purposes by diverse age groups, thereby allowing teachers to decide what level of freedom and complexity to introduce to their students. Sometimes the students follow a description to build up a certain model, and other times they explore the material and produce open design products. Figure 1 is a picture of a student-created model to give an impression of their results.



*Figure 1 Model by 4Dframe*

### **2.4. Comparison of Sweden and South Korea**

Both countries are high-tech and have long traditions of productive industry as the main means for sustaining their economies. Both countries are also very high ranked regarding being innovative (<https://www.weforum.org/agenda/2018/02/south-korea-and-sweden-are-the-most-innovative-countries-in-the-world?>).

During the last twenty years, South Korea has developed into one of the top countries when it comes to results in science and mathematics education tests (TIMSS, PISA). The current curriculum, set during a major reconstruction, has been updated every other year since 2011 in order to fit new demands in society (<http://timssandpirls.bc.edu>). Known for a school system with a high degree of success, 99% graduate from high school and 85% from university. It is also characterized by being competitive and result-oriented. South Korea has a 6+3+3+4 year education system, where acceptance to university is determined by comparing test results when students take an entrance exam during the last semester in high school.

Over the past 20 years, Sweden has undergone a downward trend in terms of education outcomes. Formerly a top performer, it has just recovered from being below average among OECD countries and is now just above average in international studies like TIMSS and PISA. But, in contrast to South Korea, Sweden introduced creativity relatively early in the national school steering documents where it's already mentioned as important in curricula emerging in the early 1990s.

### **3. THEORY AND METHOD**

Seven teachers from each country were selected as informants for this survey. The 14 represent different levels in the education system, ranging from preschool through high school. All teachers interviewed have used 4DFrame as a tool in their classes.

All were interviewed according to a semi-constructed interview technique via a questionnaire containing 12 questions as the question-base. Each interview lasted about 60 minutes.

The interviews were conducted according to a semi-constructed interview technique, where a questionnaire was used with follow-up questions asked for clarification (Kvale 1997). In total 12 questions were used as the question-base. Each interview lasted for about 60 min.

In designing the questionnaire, three overall areas formed the basis for this investigation representing several different theoretical frameworks. The intention was to conduct an overview survey to define factors that might limit the development of teaching creativity and spatial skills in the two countries.

#### ***3.1. Area 1 – teacher’s content knowledge and pedagogical content knowledge***

Teacher's content knowledge—in creativity and spatial skills—was captured by asking how the informants define the different concepts and their relation to each other. This was done to see if the teachers’ instructing at different levels in these countries had the same view of these somewhat vague concepts. The questionnaire also turned to the area of pedagogical content knowledge as some questions asked them to describe how they taught these subjects. The informants were also asked whether they thought they have had the opportunity to learn these concepts and the corresponding pedagogy through their own education, or if they felt that they needed more training in the field.

#### ***3.2. Area 2 – support by the policy documents***

We asked the interviewees about how they interpret national policy documents—their support of working on model construction, in teaching spatial skills and creativity—to see if these organizational frame factors are limiting or permissive in this type of instruction in the two countries.

#### ***3.3. Area 3 – preconditions and limitations***

Finally, we were also interested in the informant’s experiences when training students. Questions were asked about their preconditions for teaching these skills and the informants were asked to describe the limitations they saw when they could not train their students, as they preferred.

A summative analysis of answers representing these areas will hopefully give an insight into how education regarding creativity and spatial skills has been developed to date. Furthermore, we anticipate such insights will work as guidelines for developing an organisational framework in order to get appropriate training for all students.

The interviews, conducted in Korean, Swedish or English, were analysed after transcription and, when necessary, translated into English.

During analysis, answers to question were compared by either direct answers, or identifying keywords or phrases mentioned by the interviewees. Those words and phrases were then introduced into tables. Below is an example of such a table. After completion, the authors looked for differences, especially at the country level.

Table 1. An example of a table used in analysis.

Q1 “Is it important for your students to develop the ability to construct models?”	Sweden	Korea
Not at all	0	0
Not that much	0	0
Somewhat important	1	0
Important	0	1
Very important	6	6
Answers	7	7

## 4. RESULTS

### 4.1. Area 1 – content knowledge and pedagogical content knowledge

Three of the questions focused on how interviewees’ defined terminology used in this study.

One question asked them to define a creative person. The answers looked very similar when compared between both groups. Almost everyone expressed some of the following criteria, which is very much in keeping with definitions found in dictionaries and other literature.

A creative person is someone that is:

*Curious*

*Open to new thoughts and ideas*

*Dares to step away from conventions and into the unknown*

*Can provide multiple alternative solutions to a problem*

*Has ideas, but can also accomplish something*

*Can take a drawing and other references and create something new from them*

*Someone that can be creative both verbally and technically*

Two differences emerged: Korean teachers, to some extent, expressed that a creative person is someone having a lot of fundamental knowledge for solving problems. Swedish teachers, on the other hand, used the terms “dare” and “courage” more often.

When asked for the definition of spatial skills, the teachers expressed similar explanations, most often saying having spatial skills is the ability to understand and predict the conversion from two- to three-dimensional figures. One noted difference between Swedish and Korean teachers was that the former used a broader variety of explanations. They mentioned, for example, the ability to understand the movement of objects in a three-dimensional room.

The teachers were asked whether they thought it important to train their students in being more creative and having good spatial skills. All teachers from both countries agreed.

They were also asked how they taught their students in this specific sense. The results are shown in table 2. One point was given for each teacher who named the specific training method in column 1. “Learning by making” and similarly “building models” were methods for training creativity and spatial skills for most of the teachers. This result agrees with the answers when asking if it is important that students develop in model building: 12 out of 14 respondents said it is very important and the remaining two that it was important or somewhat important.

Table 2. Pedagogical methods used for training creativity and spatial skills for the 14 interviewed teachers.

Train creativity	Sweden	Korea	Train spatial skills	Sweden	Korea
Special Methodolgy	0	1	Building models	6	3



Train creativity	Sweden	Korea	Train spatial skills	Sweden	Korea
Learning by making	4	2	Reading texts	0	1
Imitate /Role Models	1	0	Think and discover themselves	1	2
Guidance from the teacher	0	1	Examples from daily life	0	1
Art	1	1	Sketching	0	2
Experiences	0	2	Spatial training, outdoors	1	0
Problem solving	1	0	Build and construct	1	1
Answers	7	7	Answers	8	10

Students were trained by making models in science and technology (11 teachers), math (10), STEM (5), design (3), art (2), language education (2) and other subjects (3).

Teachers from both countries, especially in Korea, expressed a lack of adequate training for both creativity and spatial skills. A few Swedish teachers explained that they have been self-taught by reading research literature and trying to implement the techniques from their gained theoretical knowledge. It seems that none of the teachers had such training while earning their university teaching degree.

Some teachers specifically mentioned the importance of continuous learning in this area. They found that the best way to follow and develop new trends in education was to form collaborative teams that worked together after participating in a course.

#### **4.2. Area 2 – support by the policy documents**

How do the national policy documents support teaching creativity and spatial skills using model construction in education?

All seven Swedish teachers felt that using model construction, as a pedagogical tool for various topics was a perfect match with the steering documents for all grade levels. They agreed that creativity and spatial skills were an important part of the curriculum; though not much emphasised before, they now seem to be coming to the fore more and more. The respondents also see that industry is stressing for this kind of competence: “one has to be able to think outside the box,” and that they are in the “beginning of entrepreneurial learning.” A few other teachers think that, while it is a good match, it is not easy to understand how to implement such training. Another teacher worried about such training’s future development, as focus in the Swedish school system has changed quite a bit lately. Currently, writing and reading skills are prioritised along with information that can be caught in written tests. This political change is believed to be the result of the previous decline in TIMMS and PISA test results.

Three of the Korean teachers said that using model construction is a perfect match with their steering documents. One thought that the only part of the government-mandated curriculum dealing with any sort of spatial thinking was in mathematics, geometry and vectors. Those teachers that saw a match told that it is problematic to teach those capabilities. What really counts in the Korean school system are the university entrance exams and those tests do not normally include any sections where you need to be explicitly creative or have good spatial skills. In Korea, it is also difficult for teachers to find the time to do anything outside training higher grade students for the university entrance exams. These extra subjects are more often taught in after-school groups or in classes for specially gifted students.

#### **4.3. Area 3 – preconditions and limitations**

The preconditions for Korean and Swedish teachers seem to be very similar. Half of the interviewees said that conditions were perfect: three argued they were bad and three proclaimed they saw where improvements could be made. When following up answers, it became clear that Korean teachers referred more to having modelling material at hand, whereas Swedish teachers mentioned more general preconditions: if there was training available, if school management gave time, etc. One Korean teacher shared that she had bought material for

teaching from her personal household budget. A Swedish teacher told how her administrators thought she was overly trained in the area.

Six out of 14 teachers said that they could not see any limitations: such training was only advantageous for the students. Those that pointed out limitations thought model construction took time, which might not be available due to focusing on other prioritised areas. Several mentioned that the teaching material was expensive.

When asked whether they and their school were unique for teaching students creativity and developing spatial skills, most informants thought they are extraordinary. Nine teachers believed other schools seldom taught creativity and spatial skills or just once in a while. Five thought other schools did it more often.

## 5. DISCUSSION AND CONCLUSION

Overall, the informants in this study expressed the importance of training spatial skills and creativity. Everyone were very competent; all used open model construction for teaching creativity and, to some extent, spatial skills.

In both countries, current steering documents have included creativity and sometimes spatial skills as important abilities to teach. Adequate training or examples, however, of how to approach this is lacking in both countries. This makes understanding how to take on relevant pedagogical approaches difficult.

Both Korean and Swedish participants felt a bit unique as the majority of teachers in their countries don't use model construction the same or as frequently as they do since most lack relevant training. Koreans also mentioned that such skills aren't what students or parents look for. Education's primary goal is to ensure as high a score as possible on university entrance exams.

We believe we can see proof of creativity as this potential has been in the Swedish curriculum longer than in South Korea. This is because the Korean teachers' replies related to the importance of the teaching these skills are more varied than the Swedish ones. Sweden has a greater consensus that these areas are important to teach and the curriculum seems to be more unambiguous regarding teaching creativity and spatial skills.

In Sweden, the trend in the importance of teaching these abilities, especially creativity, has been in the curriculum for too long without really being implemented. This often causes frustration and leads to these topics being less prioritised.

The South Korean informants stated that the priority given to the university entrance exams is an important—or maybe *the* most important—factor that inhibits implementation of teaching creativity and spatial skills. In spite of Korea being on top in many educational tests, teachers haven't the self-confidence to follow the curriculum, but need to teach toward the university entrance exam. They offered that new kinds of pedagogical approaches are mostly performed in after-school groups.

We conclude by stating that neither of these two countries investigated have succeeded in shaping a system where students generally receive training in being creative and/or in spatial skills. There is, however, a movement afoot that if handled properly will lead to this relatively easily and soon. Recommendations for establishing a more wide-spread and equal system are: a) provide clear policy documents explaining that this kind of training should be part of compulsory education, and b) build up teachers' subject competence and pedagogical subject competence by providing training in teacher education, as well as in continuous training for teachers already in schools.

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# Spatial Ability and Approaches to Solving Word Problems in Mathematics

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Spatial ability is regarded in cognitive psychology as a primary and fundamental aspect of intelligence that influences performance across a wide range of intellectual activities. Like all individuals, students vary in spatial ability which, in turn, impacts on the ability of each to engage with the school curriculum, particularly so in science, technology, engineering and mathematics (STEM) subjects. Those with high levels of spatial ability are more likely to be attracted to and successful at STEM subjects whereas those with low levels of spatial ability are more likely to be challenged by these subject areas and, instead, migrate towards humanities and social sciences (HSS). In this paper, findings from research that have explored the relationship between spatial ability and approaches to solving word problems in mathematics are summarised. Differences in approach between those with low and high levels of spatial ability are entirely related to the representation phase in problem solving, the phase in which the problem solver interprets the word statement and draws on linguistic, semantic and schematic knowledge to develop a mental model or representation of the problem which must be completed correctly for the following solution phase to be successful. Ways in which representation can vary among low and high spatial ability students are illustrated with examples of solutions to particular problems collected from participants during a research study. In this way, it is hoped to communicate the challenges faced by low spatial ability students as they engage with curricula such as maths so teachers can better understand how these students experience problem solving and be more able to assist them in developing problem solving skills.

*Key Words: Spatial ability, problem solving, STEM education.*

## 1. INTRODUCTION

Project Talent was a very large longitudinal study conducted in the US beginning in the 1960s in which psychometric data were collected from 50,000 boys and 50,000 girls in each of four years of high school, i.e. 400,00 participants from grades 9 through 12 (Wai, Lubinski, & Benbow, 2009). Participants were administered a battery of tests that assessed primary cognitive abilities – verbal, mathematical and spatial - and they were contacted again 11 years later to find out what education and career choices they had pursued. When grouped by education and career choice, very different cognitive ability profiles emerged between those who migrated towards humanities and social sciences (HSS) and those who opted for science, technology, engineering and maths (STEM). While broadly similar in verbal ability, the two groups differed significantly in maths ability but the largest difference was to be found in their spatial ability levels. Spatial ability, as measured in school, emerged to be a very strong indicator of which career option these young people were destined to take. Furthermore, when the engineering group was divided into bachelors, masters and PhD, based on highest degree obtained, spatial ability was found to correlate strongly with this categorisation: in the engineering group, almost one quarter of those who obtained a bachelor's degree and almost half of those who earned a PhD came from the top 4 % in spatial ability as measured in high school.

In another study with a slightly younger sample (average age = 13) of academically gifted students, participants were asked to name the most and least favourite classes they took in high school (Shea, Lubinski, & Benbow, 2001). A majority of boys (64 %) and a minority of girls (37 %) listed a maths or science class as favourite.

For both boys and girls, those who listed these classes as their favourite had significantly higher quantitative (math) and spatial abilities and significantly lower verbal ability than those who selected HSS subjects. Spatial ability was found to be a more discriminating measure than quantitative ability in this study. With regard to least favourite class, a majority of boys (84 %) and a minority of girls (48 %) listed a HSS class. A much larger gap in spatial ability was found for girls than for boys when grouped into STEM and HSS based on least favourite class. In other words, for the girls, selecting least favourite class revealed a bigger difference in spatial ability than dividing the sample based on most favourite class. From a relatively early age in education, at least at the beginning of secondary education (age 12 to 14), spatial ability is connected strongly with attraction towards and success in STEM subjects and this trend continues through secondary school and on to higher education.

Particular aspects of STEM education where performance has been shown to be significantly related to spatial ability include maths, physics concepts, electric circuits and chemistry problem solving. Spatial ability has been shown to be related to learning concepts associated with Newtonian mechanics such as frame of reference problems (Kozhevnikov, Motes, & Hegarty, 2007). In chemistry education, spatial ability has been linked to performance on non-routine problem solving (Bodner, 2015). Electric circuit analysis has also been shown to be related to spatial ability (Duffy & O'Dwyer, 2015) which probably highlights the importance of spatial ability to graphical imagery. Graphs, schematics and technical drawings, for example, are frequently found in STEM education and require the use of spatial visualisation, a factor of spatial ability. Mathematics provides a foundation for many STEM subjects and is strongly related to spatial ability across a variety of tasks and throughout development (Mix & Cheng, 2012). As in chemistry, solving non-routine problems, such as word problems, is a task that consistently reveals a relationship with spatial ability.

## 2. WORD PROBLEM SOLVING AND SPATIAL ABILITY

At a cognitive level, problem solving is considered to consist of two phases: (i) representation, a phase beginning with a reading of the problem statement and resulting in the translation of statements and selection of a schema, and (ii) solution, the phase in which procedural mathematical skills are applied following some strategy to yield an answer (Hegarty, Mayer, & Monk, 1995; Mayer, 1992). The two phases are cognitively distinct as evidenced by spatial ability being significantly related to representation but not solution (Duffy, 2017). The large array of problem solving cycles available in maths text books and websites offer heuristics that assist mostly with the cognitively more challenging representation phase. Many of these methods follow Polya's (1945, 2009) four-step problem solving model (i.e., understand the problem, devise a plan, carry out the plan, and look back and reflect) but are not necessarily based on what has been learnt about the relationship between spatial ability and problem solving.

Although the mathematics embedded in word problems can be very basic, they can be very difficult to solve because interpreting and translating word problems to mathematical form is not that easy. Several studies have illustrated how rephrasing the same problem can lead to very different success rates. For example, consider the two versions of the same problem presented in Table 1 which differed in the phrasing of the relational statement and revealed very different success rates among two groups of children.

*Table 1. Success rates for two groups of children on a problem phrased two ways (Hudson, 1983, as cited in Mayer, 1992, p. 461).*

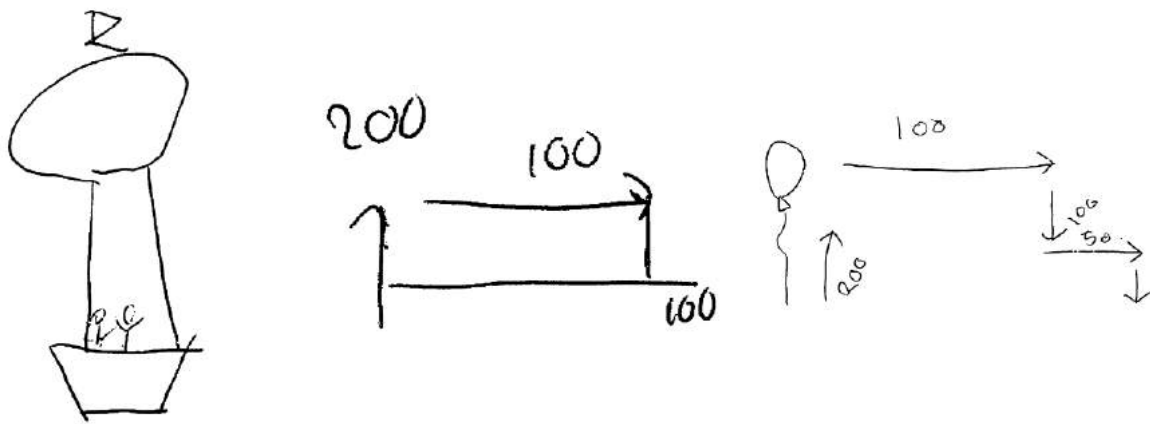
<i>Problem</i>	<i>Pre school</i>	<i>1<sup>st</sup> Grade</i>
<i>A. There are 5 birds and 3 worms. How many more birds are there than worms?</i>	<i>17 %</i>	<i>64 %</i>
<i>B. There are 5 birds and 3 worms. How many birds won't get a worm?</i>	<i>83 %</i>	<i>100 %</i>

Several other studies have also found success rate to be greatly affected by problem phrasing (e.g., Coquin-Viennot & Moreau, 2003; Hegarty, Mayer, & Green, 1992; Hinsley, Hayes, & Simon, 1977). What emerges from this research is that problem translation is quite a cognitively challenging task – errors can be made in translating the assignment of variable values and the relationships between the variables embedded in the

problem statement. Rather than dismiss these errors as a lack of careful thought one should, to borrow a principle from phenomenology, view them as the product of translating the problem as it appears to the problem solver. When presented to a sample or class group, the same problem is almost certain to be represented in several different ways. Each student develops a representation or mental model of the problem and then proceeds to solve it. While errors can be made at any stage, the representation step comes first so an error at this point will lead to failure unless the problem solver decides to review and correct it.

A small number of studies using samples of sixth grade students have highlighted the role of visualisation in problem representation. Both Hegarty & Kozhevnikov (1999) and Boonen, van Wesel, Jolles, & van der Schoot (2014) found a significant relationship between problem solving and spatial ability among two samples of 6<sup>th</sup> grade students in Ireland and The Netherlands. Participants with high spatial ability were more likely to create accurate and schematic visualisations of the problem statements and provide correct answers. Pictorial visualisations – pictures with no problem relevant details – were more associated with low spatial ability participants and higher error rates. The distinction between pictorial, accurate schematic and inaccurate schematic visualisations are illustrated in Figure 1 in response to the following balloon problem (Boonen et al., 2014, p. 18):

“A balloon first rose 200 meters from the ground, then moved 100 meters to the east, then dropped 100 meters. It then travelled 50 meters to the east, and finally dropped straight to the ground. How far was the balloon from its original starting point?”



*Pictorial visualisation*

*Inaccurate schematic visualisation*

*Accurate schematic visualisation*

*Figure 1. Examples of visualisation formed when solving the balloon problem, images and categorisations taken from (Boonen et al., 2014)*

In their data set, Boonen et al. (2014) found that two thirds of the participants solutions appeared to have ‘no visual representation’ with 47 % of these being correct, while the ‘accurate visual representation’ category was associated with an 83 % success rate, the ‘inaccurate visual representation’ category with a 24 % success rate and the final category, ‘pictorial representation’, also had a 24 % success rate. Clearly, solutions that are based on an accurate visual representation are much more likely to be correct.

In these studies visualisation qualities was determined by either looking at what the participants sketched on paper or by asking them how they solved the problem and probing how their pictures aided the solution. Visualisation requires both an ability to visualise but also depends on the application of knowledge to the problem translation. As described by Mayer (1992), problem solving can be viewed in terms of types of knowledge required: problem representation draws on linguistic, semantic and schematic knowledge while problem solution draws on strategic and procedural knowledge. Using the balloon problem to illustrate: semantic knowledge is required to understand what a balloon is and that ‘rose’ and ‘dropped’ are vertical displacements; linguistic knowledge is required to associate the values provided with the correct arithmetic

operations ('moved to the east' is the same as 'traveled to the east'; both are in the same direction so are added); and schematic knowledge is required to identify the schema for this problem which is displacement = the sum of distances on the relevant coordinate axis.

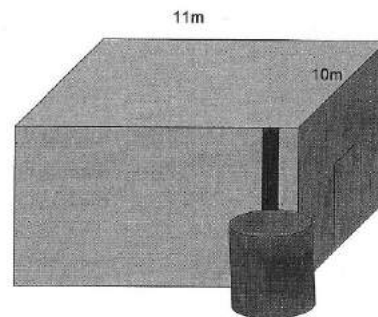
Using Mayer's knowledge framework, Duffy (2017) found a significant relationship between spatial ability and consistency in applying linguistic and schematic knowledge to problem representation when solving word problems in mathematics among a sample of first year engineering students. Success in translating assignment and relational statements and selecting schemata during problem representation was positively correlated with spatial ability. In the following Jug problem, representation required the matching of a height and volume – either 1 litre with 8.84 cm or 2 litres with 17.68 cm – and the selection of a cylinder volume schema.

“Stainless steel cylindrical jugs are made to hold a volume of 2 litres ( $2000\text{ cm}^3$ ). If the 1 litre mark is at 8.84 cm what is the **radius** of the jug to the nearest centimetre?”

Problem solution then required recall of the cylinder volume expression, the equating of this with the selected volume and extraction of the unknown radius. Excluding those who failed to recall the correct cylinder volume expression, a marked difference in ability to correctly match height and volume was found between those at the median or higher and spatial ability and those below: 88 % of those in the high spatial ability group made a correct match whereas just over half, 54 %, of those in the low spatial ability group could do so.

In the following Rain problem, representation included a volume transfer from a prism, the roof, to a cylinder, the barrel.

“The diagram shows the dimensions of a flat roofed commercial shed. During one week 5 mm of rain fell on the roof of the shed. The rain was collected by gutters that flowed into a cylindrical water barrel with a diameter of 1 m. By how much did the depth of the water in the barrel increase as a result of this rain?”



A large number of participants failed to show evidence of volume transfer with 58 % of those below the median spatial ability making this error versus 27 % of those above. A common alternative representation was to ignore the roof altogether when solving this problem and view the rainfall amount as being equivalent to the change in barrel height which led to an incorrect answer of 5 mm. Those below the median in spatial ability were three times more likely to make this error in representation.

Those weak in spatial ability face a much greater challenge in representing word problems as evidenced through the visualisations they produce and how they apply linguistic and schematic knowledge to translating the problem statement. Both of these aspects are intertwined – is visualisation the result or the process of thinking about the problem? Can one have excellent visualisation ability but lack the linguistic and schematic knowledge needed for these problems? As shown by Boonen et al. (2014), success rates are close to 50 % when there is no evidence of visualisation so it appears visualisation is not essential for success. However, based on the work by Duffy (2017), it is likely that a majority of these correct solutions came from those high in spatial ability. In other words, even when visualisation is not in evidence, success in word problem solving is still related to spatial ability.

### 3. IMPLICATIONS FOR TEACHING MATHS WORD PROBLEM SOLVING

Those wishing to teach word problem solving skills should first view the task as containing two cognitively different challenges – problem representation and solution – with the former being the area where those weak in spatial ability need assistance. Procedural mathematical knowledge that is needed in the solution phase is not discussed here as it appears to be much less related to spatial ability. In the sample used by Duffy (2017) there was no significant difference in the procedural knowledge levels of low and high spatial ability students. The challenge for low spatial ability students lies in problem representation and, hence, efforts to improve

problem solving skills should be focused on it. Two directions can be taken depending on the extent to which spatial ability is seen as a causal factor in the relationship – improve spatial ability or develop coping strategies.

Given spatial ability is a primary aspect of cognition, it is equally worthy of development as verbal and maths abilities and should lead to enhanced performance on a range of STEM tasks including problem solving. Spatial ability training has been shown by Sorby and colleagues to lead to significant gains in spatial ability, retention rates and grades in certain subjects among first year engineering students (Sorby, 2012; Sorby, Casey, Veurink, & Dulaney, 2013; Sorby & Veurink, 2010). Based on a meta-analysis of training studies Uttal et al. (2013) found evidence to support the notion that spatial ability can be improved through tailored learning interventions. Research has shown such improvement can transfer to performance in STEM education which is very promising but it is claimed that more studies are required to verify the causality of the relationship (Stieff & Uttal, 2015).

Another option for students weak in spatial ability is to learn coping strategies to improve success. As shown by the work on visualisation in problem solving, those who produce accurate schematic representations are much more likely to answer the problems correctly. Therefore, students should be made aware of how useful visualisation is by the teacher prompting them to create visualisations, reflect on their quality, improve them and spend time practicing visualisation on different problem types. An instruction to ‘draw a diagram’ in a problem solving method is misguided as it is the quality of the diagram in terms of accuracy and schematic content that is essential for success. The emphasis should be on visualisation quality.

Another potential coping strategy is based on memory models of cognition which link spatial ability to the visuospatial sketchpad, a primary aspect of working memory (Baddeley & Logie, 1999). This implies that those weak in spatial ability will begin to struggle as the number of items contained in a problem increases; problems that require many items to be processed in memory place a greater demand on working memory so those who have a higher working memory capacity will be more successful. If these problems require greater use of the visuospatial sketchpad then those with higher spatial ability will have more success. Word problem statements typically contain several assignment and relational statements and, as shown by Duffy (2017), those weak in spatial ability struggle to be consistent in translating these to mathematical form. If this is due to visuospatial working memory overload, a solution is to avoid representing the problem in one go as errors will follow a failure to hold together in working memory the large number of items contained in the statement. Instead, the problem solver should identify and treat each linguistic aspect in turn by highlighting or translating just one assignment/relational statement at a time. The problem solver should realise his/her working memory can be overloaded and act accordingly. Selecting an appropriate schema might be a different challenge in that judgement is required with recall needed from long term memory but this too may be facilitated by ignoring all but schema selection and allowing as much attention as possible to be focused on this task.

#### **4. SUMMARY**

Spatial ability is a primary factor of intelligence but its development, compared to verbal and mathematical abilities, receives much less attention in the school curriculum. Yet, it has been shown to be a key indicator of attraction towards STEM education and careers with this relationship in evidence by the end of primary school. Data from school entrance examinations that include spatial ability tests could be checked to see if this pattern holds in different locations. One area of STEM education where performance has been shown to be significantly related to spatial ability is word problem solving in mathematics. Problem representation is complex, is facilitated by visualisation and requires consistency in the application of linguistic, semantic and schematic knowledge. Problem solving skills could be improved by paying greater attention to visualisation quality and avoiding working memory overload. More research is needed to evaluate such interventions among students in all levels of education.

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# A National Spatial Skills Research & Development Project

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Over the last twenty years, considerable effort has been made to increase the number of female students in STEM education and ultimately pursuing STEM careers. These activities and initiatives have tended to focus on promoting STEM careers and attempting to make STEM education more attractive. While the objective of the national STEM education research and development project described in the paper is also to increase the number of female students in STEM education, it aims to do so by focusing on a potential cognitive barrier to STEM education: spatial ability. Multiple studies have shown that students with high levels of spatial ability are more likely to be attracted to and successful in STEM education. As part of the ongoing STEM education project described here, spatial ability tests are being administered to Irish second level students in all years (first to sixth year) across the country. The students' spatial abilities are then analysed in the context of profile data such as age, gender, subject choices, career and higher education plans and the students' perceptions of mathematics. Findings from a preliminary study of first year and transition year students showed a clear difference between male and female students' spatial ability, where the male students outperform the female students. Although the full project is still ongoing, the data from approximately 7000 students show that the male students consistently score higher on the spatial ability tests across all years of study. While a representative sample is still to be achieved, the findings indicate that the gap in spatial ability between male and female students may be increasing with age. The findings from this research project are being used to develop, deliver and evaluate an education course and learning activities specifically aiming to develop spatial ability.

*Key Words:* Spatial ability, gender, STEM education.

## 1. INTRODUCTION

While spatial ability has been defined in many different ways and described by multiple terms such as spatial skills and spatial reasoning, it is, in general viewed as a separate measurable and fundamental factor of intelligence, in a similar manner to mathematical and verbal skills. For instance, Thurstone (1950) thought of intelligence as consisting of seven principal factors; verbal comprehension, verbal fluency, number, perceptual speed, inductive reasoning, spatial visualization, and memory. McGee (1979) thought of spatial ability as consisting of two separate and distinguishable categories: spatial orientation and spatial visualization, while Lohman (1996) thought of spatial ability as having three factors: spatial orientation, spatial visualization, with the addition of spatial relation. In a meta-analysis study conducted over a decade of research Linn and Petersen (1985) suggested that spatial ability consists of three categories: spatial perception, mental rotation, and spatial visualization. Spatial ability has also been linked to Spearman's original conception of general intelligence or "g" (Spearman, 1904). From the perspective of the study described in this paper, spatial ability is viewed as the generation, retention, retrieval and transformation of visual images.

## 2. LITERATURE REVIEW

Spatial ability has been consistently linked to achievement in STEM education, most notably through Project Talent (Wai, Lubinski & Benbow, 2009). In this longitudinal study, psychometric data, testing verbal, mathematical and spatial abilities, were collected from 200,000 boys and 200,000 girls from grades 9 through 12 in the USA. The students were contacted 11 years later to identify education attainments and career paths. The study showed that the spatial abilities of these students were significantly better predictors of their STEM attainment in later years than their mathematics or verbal abilities. While the students who excelled in the fields of humanities and social sciences had similar verbal abilities, as measured in grades 9 to 12, as those who excelled in STEM, they had significantly lower mathematics and spatial abilities. In another study (Shea, Lubinski & Benbow, 2001), students' spatial abilities were measured and they were asked to identify their most and least favourite subjects in school. Students who chose a STEM subject as favourite had significantly higher spatial abilities than those who chose a humanities subject. Hence, from these and similar studies, the relationship between spatial ability and success in STEM is now widely accepted leading the National Science Board (USA) to state in its report 'Preparing the Next Generation of STEM Innovators (2010)', that the search for 'STEM talent', which is traditionally sought from those with high verbal and mathematics skills, should expand to include high spatial ability.

However, research studies have also consistently shown that female students have significantly lower spatial skills than their male counterparts, particularly in the ability to rotate three-dimensional objects (Voyer, Voyer & Bryden, 1995; Halpern et al. 2007). In one such study Lippa et al. (2010) clearly showed that women lagged behind men on spatial ability (as measured by the Mental Rotations Test) consistently across 53 countries. While the reason for this difference is not fully understood and debated in the literature, the gender difference has been documented as early as age four (Levine et al., 1999). Spatial ability and reasoning skills have also been linked to performance in mathematics and problem-solving (Duffy, 2017), while the gender difference has also been found with students having high spatial ability tending to have strong mathematical abilities – a skill set that is inherently important in the STEM disciplines (Wai et al. 2009; Casey et al., 1995).

In the context of the significant gender differences and the link between spatial ability and success in STEM, perhaps it is not surprising that the many initiatives to attract more female students into STEM education by simply promoting STEM and outreach activities have had limited success. Hence, there is an ever increasing emphasis on the need to increase STEM uptake and participation among female students at second level education. In turn, there is now an increasing awareness of the importance of developing spatial ability in order to aid success in STEM (Uttal et al. 2013; Newcombe 2010). Fortunately, through STEM education research and development, interventions and learning activities have been developed to improve students' spatial ability. Uttal et al. (2013) conducted a meta-analysis of spatial skills training, and found that spatial ability is indeed malleable, and responds well to training. They found that this training also lasted over time and it is transferrable, a key finding for investigating the implications and effects on performance in STEM subjects and disciplines and that spatial ability training is equally effective for both males and females. Interventions, which have been tested and amended in higher education over many years, have produced impressive results in terms of attracting students to STEM education, increasing retention, improving students' abilities in STEM subjects and preparing more female students for STEM disciplines (Sorby 1999; 2009).

## 3. METHODOLOGY

There is a clear diversity gap caused by the relatively low number of female students choosing STEM education paths and careers. By focusing on spatial skills, a cognitive barrier to STEM, there is great potential to increase the number of students, particularly female students, pursuing STEM education. This project builds on, and stems from, multiple research studies, which examined the relationships between spatial skills and success in STEM in higher education in Ireland. Hence, upon successful completion, this project will produce a comprehensive picture of spatial skills levels and the relationship with STEM education across all levels of Irish education.

The project is divided into two separate sub-projects:

- Measuring Spatial Abilities and Identifying Relationships

- Designing, Implementing and Evaluating Education Interventions

The objectives of the first sub-project are to:

- Measure current levels of spatial ability across second level education in Ireland with a particular focus on the gender differences;
- Identify relationships between spatial abilities and data pertaining to demographics, profile, subject choice, subject level, higher education discipline choice, perceptions of mathematics and preferred career path;

This phase of the project started in February 2017 is ongoing with approximately 7000 second level students completing the spatial skills tests and surveys to date. A preliminary study was first undertaken focusing on first year students (12 to 13 years old) and transition year students (15-16 years old). The purpose of that study was to develop robust communication protocols with the second level schools; develop effective, efficient and practical testing and surveying techniques; and to develop and have approved through the Research Ethics Committee, data acquisition and management protocols. Paper-based tests and surveys were administered to approximately 2500 first year students and 360 transition year students across 28 schools. The evaluation of the preliminary study led to the development of an online test and survey that would be used for the second phase of testing across all years (first to sixth) in a representative sample of Irish second level students.

Within this study, two different spatial ability tests are used to gather the spatial ability data: the Differential Aptitude Test: Spatial Relations (DAT:SR) and the Purdue Spatial Visualisation Test: Rotations (PSVT:R). Shortened versions of both these tests were used in order to ensure that the testing schedule in the schools was viable. For instance, the full PSVT:R test has 30 questions from which 10 were chosen for this project. The 10 questions were chosen from the analysis of spatial ability data from over 1000 students, including second level and higher education students, completing the 30 question tests. The outcome from the analysis of the 10 questions showed a correlation of 0.92 with the outcomes of the analysis of the 30 questions.

Students typically enter second level education in Ireland at about 12 years old. In the first three years students complete a range of subjects which includes the three mandatory subjects: mathematics, Irish and English. The range of additional subjects offered to the students varies across schools and includes science, technical drawing, art, music, French, German, history, geography and so on. At the end of third year the students complete state examinations, the junior certificate, within which they can take each subject at a higher or ordinary level. After completing third year students can opt to take Transition Year (fourth year) or progress directly onto fifth year. As the purpose of transition year is to focus on the development of personal and professional skills, in addition to formal academic course, the learning activities can include work placements, group projects, and community and outreach opportunities. In the latter two years of second level education, fifth and sixth years, the students typically choose 4 subjects in addition to the mandatory subjects, again at ordinary or higher level. At the end of sixth year, the students complete a final set of state examinations: the Leaving Certificate. The students are awarded points based on their results in these examinations which are used to access higher education in Ireland.

Measuring the spatial abilities of the second level students across all years (first to sixth year) started in October 2017. In addition to completing the two spatial tests, the students complete a questionnaire to ascertain demographic and profile data, such as subject choice and their perceptions of STEM. The spatial ability data was then analysed in conjunction with demographic data (age, gender, subjects, year, level etc.) to identify relationships/trends. Schools were selected to ensure a representative sample of the approximately 360,000 second level students across 700 post-primary schools in Ireland. There are also four different types of school: secondary; vocational; comprehensive and community, which can be further categorised by geographical locations (urban/rural), socio-economic status, private or public, Irish or English language, size (ranging from about 150 to 1500) and gender (mixed/boys only/girls only). The process of selecting and communicating with schools was assisted by the Professional Development Service for Teachers (PDST). To date, 51 schools have participated in the project and 7109 students have completed the tests and survey.

The second sub-project, which will be documented in future reports and publications, involves the delivery and evaluation of a spatial skills course in a small number of second level school in Ireland. The course that is currently being delivered to transition year students in six schools and to first year students in two schools, was

developed by Sorby (1999). Since the project began, 40 second level teachers have completed a two-day training course supported by the Professional Development Service for Teachers. Each delivery of the course is evaluated and subsequent changes made to adapt the course for second level in Ireland. The impact on the students' spatial ability will be examined along with any change in their perceptions of STEM education.

#### 4. RESULTS

Figure 1 below shows the spatial skills scores of 2397 first year students in second level schools in Ireland. The data, which are from the preliminary study from the first phase of the project, show a relatively small gender difference in spatial ability with the male students on average slightly outperforming the female students.

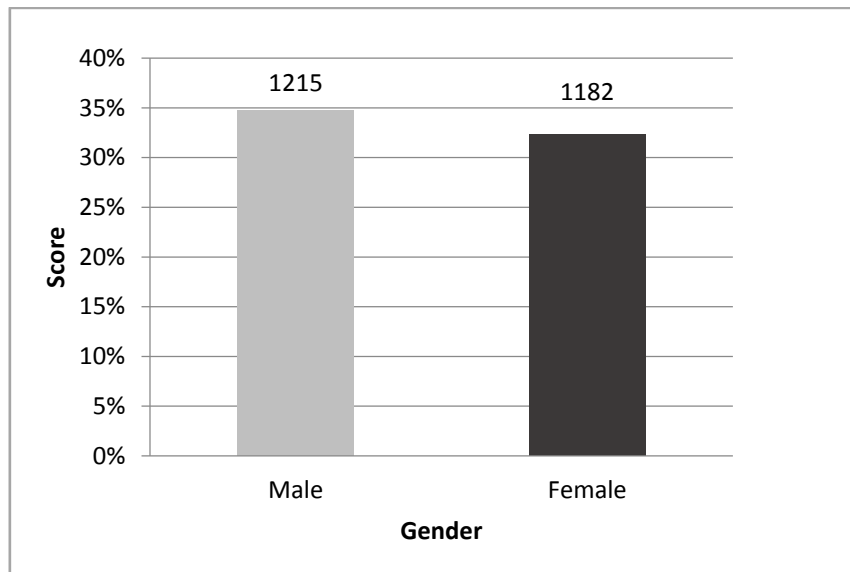


Figure 1: Preliminary study data for spatial skills score of 2397 first year students by gender.

Figure 2 below shows the same spatial ability data for the 2397 first year students by age and gender. Although the number of 14 year old students is low, the data indicate that spatial ability is increasing with age.

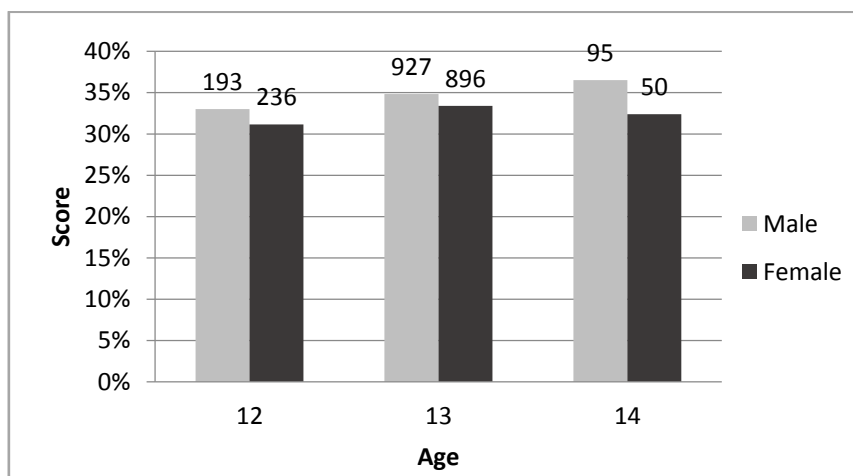


Figure 2: Preliminary study data for spatial skills score of 2397 first year students by age.

The increases in spatial ability as students progress through second level education can be seen in Figure 3. While the increases are still small, there is clear progression from year 1 to year 3 but the gender gap also increases across these years. It is difficult to interpret the data from Year 3 to Year 5, as many students progress directly into Year 5 from Year 3, thereby skipping transition year (year 4). However, the data clearly shows that the difference in average spatial ability between male and female students is small in year 1 but has increased significantly by year 6.

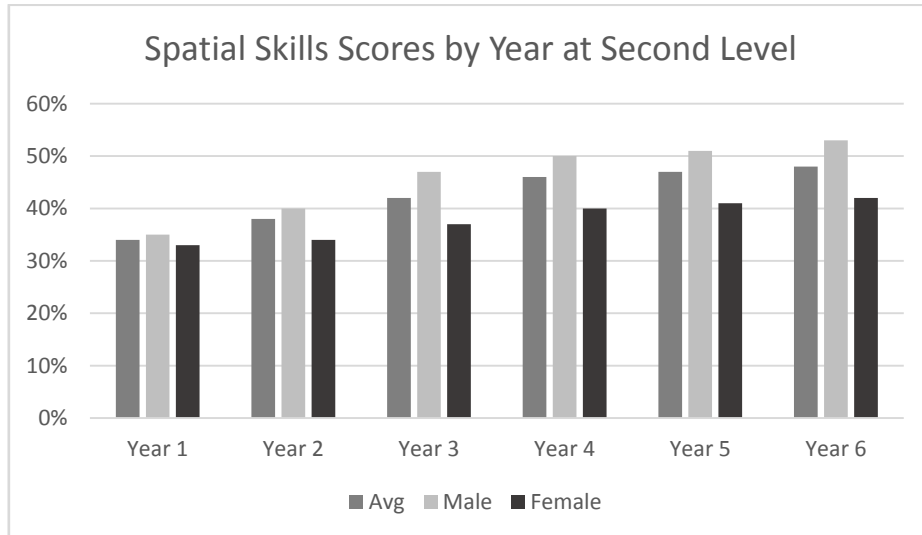


Figure 3: Data for spatial skills score of 4509 students from first to sixth year by gender and year.

It should be noted that these are preliminary data that indicate potential trends and relationships. A representative sample of data has yet to be obtained but when it is, the impact of subject choice, and types and categories of school on spatial ability will be carefully examined.

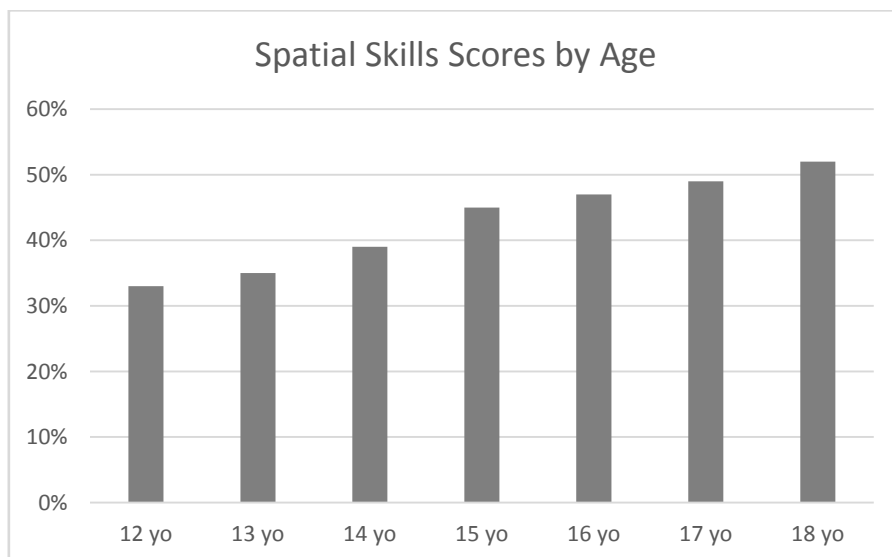


Figure 4: Data for spatial skills score of 4509 students from first to sixth year by age.

Figure 4 shows the students' spatial ability increases with age. As a comparison, the average score of students (average age of 18 years old) entering STEM programmes in Dublin Institute of Technology in the same test of spatial ability was 66%.

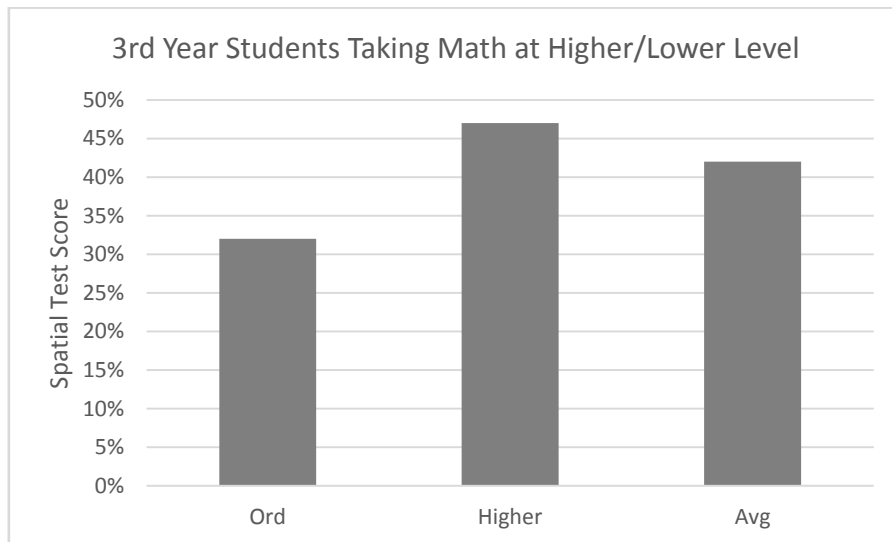


Figure 5: Data for spatial skills score of third year students by level of mathematics taken.

Figure 5 shows the spatial ability scores of third year students by level of mathematics taken in the Junior Certificate. It clearly shows the spatial ability score for students taking ordinary level are significantly less than their counterparts taking higher level mathematics. In the survey students were asked to rate on a Likert scale from 1 to 5 (1 being they dislike maths) and the results from the first year students are shown in Figure 6. These data show that students who dislike the subject of mathematics tend to have relatively low spatial ability while students who like mathematics tend to have relatively high spatial ability.

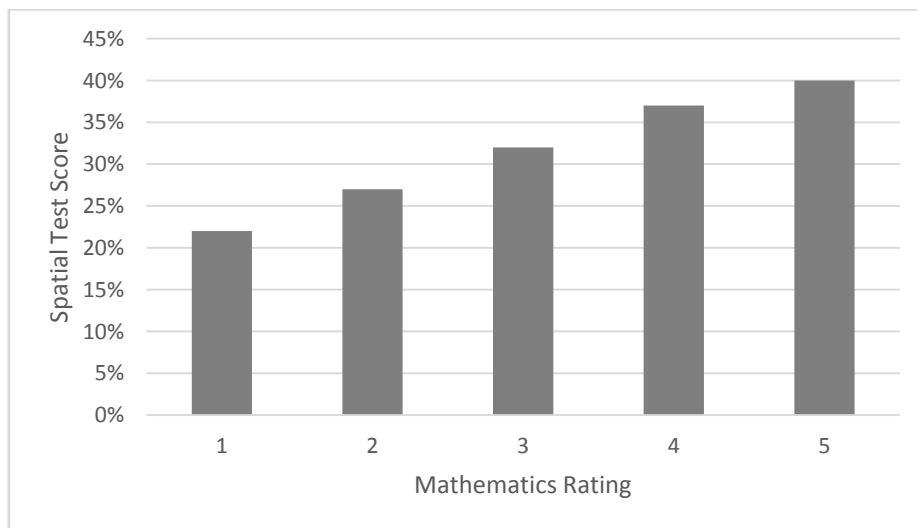


Figure 6: Data for spatial skills score of 4509 students by mathematics rating.

When the average spatial abilities were calculated for the students in each higher level subject in sixth year, the subjects with highest average scores of spatial ability were all in the STEM area:

- Chemistry (61%)
- Physics (60%)
- Digital Communications & Graphics (59%)
- Mathematics (59%)

When sixth year students were asked about the Higher Education discipline that they plan to pursue upon completion of the Leaving Certificate, the data again shows a clear relationship between STEM and spatial ability. The average spatial ability score of the students intending to pursue STEM education in University is

60% while those planning to take an Arts or Humanities University course had an average spatial ability score of 41%.

From a sample of 511 students asked to select their favourite subject, 29% chose a STEM subject (e.g. mathematics, physics, chemistry, etc.) while 71% chose a subject under the category of arts, humanities and business (e.g. art, Irish, English, history, etc.). The students choosing mathematics and physics as their favourite had the highest average spatial ability scores of 60% and 61% respectively.

## **5. DISCUSSION**

The data indicates that students' spatial ability does develop as they get older and progress through second level education. This development may be caused by a combination of formal learning and typical activities outside of the school, such as sports, video games and so on. However, the increase is relatively small and does not bring the average in sixth year to a level typical of first year STEM students in higher education. As spatial ability has clearly been identified as an important cognitive factor for success in STEM education, the finding from this preliminary analysis of the data obtained to date indicates that many second level students are not equipped to engage in STEM education. Furthermore, the data here shows that there is a significant gender gap favouring males that increases as students progress through second level. If confirmed through the full analysis of the representative data, this could partly explain the relatively low number of female students choosing STEM education and careers. It also points to the importance of developing spatial ability at an early age, as the gap widens and as the age and year increase. Early interventions to develop spatial ability could have a positive effect on their perceptions of STEM subjects and increase their aptitude and success in these subjects and disciplines.

It can be expected that students who are successful in a subject will tend to hold positive views of that subject. The data here shows that students with higher spatial ability tend to have more positive perceptions and attitudes towards mathematics, a key STEM subject. Given their relatively low spatial ability, it is unlikely that students taking ordinary level mathematics in the Junior Certificate will choose a STEM education or career path. Spatial ability has been linked to mathematics ability in many studies, and this finding indicates that education interventions in transition year may be too late and if spatial ability can be developed earlier perhaps more students would be equipped to take the higher level mathematics.

The data shows that clear relationship between spatial ability and subject choice in the Leaving Certificate and ultimately discipline choice in higher education but only a minority of the students sampled chose a STEM subject as favourite and planned to choose STEM at University. When the distribution of spatial ability data is examined it is clear that only a minority of the students are likely to successfully engage in STEM education.

## **6. CONCLUSIONS**

Although this research study is still in progress and a representative sample of data has not yet been obtained, the data suggest many interesting findings. These findings may shed some light on the reasons behind the relatively low number of female students pursuing STEM education and careers in Ireland. They may also explain the reason for the relatively limited success of the many promotion and outreach initiatives over the last 15 years aimed at increasing the number of female students in STEM education. Findings from many previous research studies have shown the link between spatial ability and success in STEM education and this study found that there was a clear difference between spatial ability for male and female students. Furthermore, while the findings indicate that spatial ability increases with age as students progress through second level, the gap between the spatial abilities of male and female students also increases. This phenomenon will be examined fully when a representative sample has been obtained and in the context of the evaluation of the spatial skills courses currently being delivered in six schools. The data will also be benchmarked against data from a similar study internationally.



## 7. ACKNOWLEDGMENTS

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# Maker education in the English context

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Ten years ago, Steeg (2008) asked whether making, hacking and fabbing might be the future for d&t education. Since then much has changed. Across the world the 'maker movement' has grown enormously, evidenced by the large numbers of maker spaces and maker events that have sprung up, and the appearance of a significant literature. In the USA, Maker Education has been a strong strand in the maker movement's development and has made some significant advances in schools. Arguably two factors have aided this; the first is the general weakness of Technology Education as a mainstream subject for all and the second is a willingness in many quarters to embrace STEM (or STEAM) as a context for teaching (a willingness that is much less evident in England) that maker education can readily respond to. In England too, the maker movement has grown in numbers and profile and there has been some policy interest. But there has been little significant development of an identifiable 'maker education' strand in mainstream schooling. Over the same period, the content of D&T in the English curriculum has been strengthened through new national curriculum content for children aged 5-14 and a new GCSE specification, while simultaneously education policy has weakened the subject's position in schools, to the point of precariousness in some places. This paper explores these developments, examining the differences in the development of maker education in the USA and England. It asks what lessons the English context can learn from the US maker education movement, discussing ways of developing an approach to maker education that is sympathetic to the English context. The importance of building alliances will be emphasised. This will entail developing understanding and mutual support between two very different cultures and suggestions will be made as to how this might be achieved.

*Key words: Maker Education, Maker Movement, Curriculum Developmen*

## 1. THE DEVELOPING MAKER 'MOVEMENT'

'Maker' is a term that has emerged into widespread use in the last 10-15 years. It is used to describe people who like to make stuff, often, but not always, using high technology tools (microcontrollers, laser cutters, 3D printers, for example) and in some cases designing and making such tools themselves. It is a largely self-defining term (anyone can call themselves a maker; there is no test to pass) and takes in a broad swathe of interests that include crafting, heavy engineering, electronics, embedded control, programming, robotics and biotech, amongst many other things. There is a strong preference amongst makers towards open-source hardware and software tools and a broad understanding that the products they make should be covered by 'open' licences, such as those from Creative Commons (2018) and the Open Source Initiative (2018), thus allowing them to be developed and modified (hacked) by others; this world view is summarised in the Maker's Bill of Rights (Makezine, 2006) and the Open Source Hardware Association's (2018) definition. It should be noted that, already, the terms 'Maker' and 'Maker Movement' are contested terms (Grace-Flood, 2018).

The things that makers produce may appear quirky and are often produced for themselves or their immediate community (rather than being made with an immediate eye to mass production), Gershenfeld et al (2017) suggest that facilitating making for a market of one is one of the prime purposes of a FabLab. Often, products are a result of 'tinkering' or 'playing' with materials (Gabrielson, 2013, Wilkinson and Petrich, 2014). However, there are also examples of things created by makers becoming the basis of a commercial company – many products on funding sites like Kickstarter (2018) have their origins with makers.

The human imperative to make stuff is hardly new. DIY and craft activities have been around a long time and became more of a leisure pursuit and less a necessity during the second half of the last century. What is new is the development of the DIY mindset into a more community-oriented (Do-It-Together (DIT)) approach supported by a collection of digital tools and resources that have enabled people to do more and to communicate better. These include the rapidly dropping costs of digital manufacturing tools, the availability of powerful open software, the rise of open hardware, online social networks and, importantly, the growth of community spaces where makers can gather (Dougherty and Conrad, 2016).

Two key events happened in 2005. One was the publication by Neil Gershenfeld of 'Fab' (Gershenfeld, 2005), a book that detailed the development of a making course at MIT open to all students and the subsequent creation, as a spinoff, of what he called a FabLab (Fabrication Laboratory). FabLabs are workshops stocked with state-of-the-art but low cost digital designing and making tools with a focus on community use (Walter-Herrmann and Büching, 2013). At the time of writing, there are 1270 FabLabs worldwide (taking in every continent except Antarctica), including 41 in the UK (FabLabs, 2018). Gershenfeld et al (2017) describe the growth of FabLabs as following 'Lass' Law' (by analogy with Moore's Law for integrated circuits), with the number of FabLabs worldwide doubling roughly every 18 months.

Also, in 2005, Maker Media was launched along with the publishing of Make magazine and its associated website. The website (Makezine, 2018) has grown to include a shop of equipment and resources for makers as well a large and growing repository of step-by-step maker projects. In 2006, Maker Media ran the first Bay Area Maker Faire, with the strap line: 'The Greatest Show (and Tell) on Earth'. In 2017, the 12th Bay Area Maker Faire hosted over 2,000 exhibits and 125,000 attendees. In fact, by 2017 there were 220 Maker Faires in 45 countries, including eight in the UK, with more than 1.5 million visitors (Maker Faire Fast Facts, 2018). These numbers are likely to grow again in 2018. Maker Media and makers generally received a significant boost in the USA when president Obama started to host Maker Faires at the White House (Fried & Wetstone, 2014) and famously referred to the important role of makers in the development of the USA (Obama, 2014). And Maker Faires are not the only organised gatherings of makers. In the UK, for example, there has been a trend to look past Maker Media and develop home-grown events for makers varying from small one-day affairs to large camping weekends organised on similar principles to rock festivals.

As the above has suggested, FabLabs and MakerMedia are significant influences, but they are just two facets of the wider maker community, which is incredibly diverse. Across the world makers get together to hack, make and tinker in a wide range of settings from informal gatherings in cafes and libraries, through a wide range of 'makerspaces' and 'hackspaces'. In the US, 100K Garages (2018) is just one of a number of organisations that helps connect makers with each other and to those with fabrication facilities. There is a number of sites dedicated to sharing maker projects each with a different emphasis and revenue model. The UK Hackspace Foundation (2018) lists 69 affiliated hackspaces, but this certainly isn't the total number of makerspaces; NESTA (2015) identified 97, acknowledging that that was certainly not a complete record. Corporations and universities, too, are taking interest, setting up their own makerspaces, sometimes for solely for their own staff (and students), sometime with a broader community aim. In the UK the Guild of Makers (2018) has recently been established to help makers hoping to make a living from their activity put their activities onto a professional footing. Also in the UK, the Raspberry Pi Foundation has launched its own magazine and platform for makers, (Hackspace, 2018), bringing a welcome (in the UK, at least) focus on making that isn't US-centric.

## **2. TRENDS IN MAKER EDUCATION**

### ***2.1 In the US***

The Maker Movement in the USA has developed a high profile in roughly the same period that Technology Education has experienced a decline in prominence. A move to a more traditional and narrowly focussed approach to education, linked to high stakes assessment and driven by the 'No Child Left Behind Act', has left many searching for different ways of approaching education. The rise of STEM (or STEAM) as a context for teaching has been one response but, as Moye et al (2012) observe, very often the focus is on the 'S' and the 'M' and Technology Education is side-lined.

One of the drivers for developing a 'maker' approach to education been simply a desire to give a wider audience of children an experience of the satisfaction of making that is observed in working with young people in maker spaces. For others, maker education offers the possibility of revitalising technology education and re-emphasising its place within STEM. What has developed as a result is several strands of maker education, each with its particular approach but generally seeing each other as allies. What broadly unites these strands, in terms of learning theory, is an approach to learning based on constructivist and, particularly, constructionist views of learning (Papert 1993, Kafai & Resnick 1996) that emphasise making as a powerful lever to support learning. The core argument of constructionism is that people learn best when they are making (constructing) something, be it a sandcastle on the beach or a theory in physics, because of the powerful interaction between thinking and action during making. In this view, learning is most powerful when two conditions apply; the construction environment is rich and there is ample opportunity to view the success of one's construction efforts (feedback); conditions that both Technology Education and maker education are well-placed to meet. However, it is evident that the various approaches to a maker education seem to place little emphasis on Technology Education, either the Technological Literacy standards (ITEEA, 2007) or ITEEA itself - and the detachment seems reciprocal as ITEEA appears to have little to say about maker education.

Prominent strands of maker education in the US include:

- Maker Media have been active in developing a maker education strand, winning significant federal money, for example from DARPA (Dougherty, 2012), followed by substantial funding from industry, e.g. Cognizant (Dorph & Cannady, 2014), to set up the Maker Education Initiative (MakerEd, 2018). The aim here is to develop maker spaces associated with schools and the Initiative has developed a wide range of resources to support these educational makerspaces, many of which are freely available from their website. Because of the very diverse nature of the US education system this initiative is focused, at least to start with, on extracurricular activity.
- Agency By Design is a research project based within Harvard's Project Zero with a particular focus on exploring appropriate pedagogies and assessment tools for what they call maker-centred education (Clapp et al, 2017). Much of their thinking is informed by associated Project Zero strands of work focused on 'making learning visible' and 'making thinking visible' (Ritchhart et al, 2011). The schools involved in this research project have maker rooms that are used within the curriculum for broad cross-curricular activities; there is appears to be no desire to see maker-centred learning as a separate subject but rather a broad approach to learning that can have wide benefits.
- Design, Make, Play (Honey & Kantor, 2013) arises from work at the New York Hall of Science and focuses on extra-curricular settings including museums and community centres as well as schools and on-line.
- Constructing Modern Knowledge is firmly and explicitly based in constructionism and focuses on developing a maker approach to learning within schools and supports its aims through a wide range of books and CPD activities (Martinez & Stager, 2013).
- FabLearn, is a research initiative based at Stanford University, that has built an international network of FabLearn Labs that link universities with schools and are supported by FabLearn Fellows. Fablearn supports educators through a range of publications, CPD and conferences (Blikstein et al 2016).
- Fab Academy has grown out of the FabLab network to meet the needs for structured content for FabLab users, for local learning support and for accreditation of that learning. The core audience for the Academy is FabLab users and whether these users happen to be school-age is incidental. The core pedagogical approach is derived from MIT's "How to Make (Almost) Anything" course (Gershenfeld, 2005) but has grown to include biotechnologies ("How to Grow (Almost) Anything") (Gershenfeld et al, 2017).
- MIT's Lifelong Kindergarten is at the heart of constructionist thinking and is focussed on developing technologies that support constructionist pedagogies including the scratch programming language and the MakeyMakey interface for physical computing. The Computer Clubhouse network of out-of-school learning settings is an offshoot of the Lifelong Kindergarten. More recently they have started to provide CPD work aimed at helping teachers develop these approaches within schools (Resnick, 2017).

A small number of US schools have bent their structures to embrace making as a core element of their curriculum. Prominent among these is High Tech High (2018) a network of 12 charter schools (roughly equivalent to a Multi Academy Trust in England) in San Diego. Even more radical is Brightworks (2018), a

private school where the whole curriculum is built around collaborative, mixed-age projects in which making is a core activity.

## **2.2 In England**

There has been limited maker education activity in England. Some makerspaces make forays into education. FabLabs usually have an educational aim as a part of their brief and other makerspaces have offered both extra-curricular activities aimed at young people and within-curriculum projects. It is noticeable, and perhaps inevitable given that makerspaces aren't generally staffed by teachers, that there can be something of a deficiency of awareness about the current state of the art of technologies available within D&T education (at least in principle; the capability of school D&T departments is highly variable).

There has been some institutional interest in maker education in England. Tinkering for Learning (2018), based at the University of Manchester has been exploring whether a maker (tinkering) approach can improve school pupils' understanding of engineering (Bianchi, 2016). The Centre for Real World Learning has also taken an interest in making as an approach to learning (Lucas et al, 2012). The Comino Foundation (2018) has an enduring interest in developing practical making skills in young people and funds a number of initiatives including the two previously mentioned. However, the reach of these of these projects has been limited and we explore possible reasons for this in the next section.

A small number of school-based makerspaces have been explored in England though few have, as yet, come to fruition. Spark (2018) is one that has actually opened, in early 2018, at Penketh School with an aim of "weaving maker education into our curriculum". It is early days for Spark in exploring how this weaving will take place and we will be watching with interest. It is a measure of the novelty of a makerspace in an English school, that Caroline Keep, the teacher who has driven the project, has been shortlisted for the Times Educational Supplement's 2018 New Teacher of the Year Award (TES, 2018).

## **3. IS THERE A FUTURE FOR MAKER EDUCATION IN ENGLAND?**

### **3.1 The context**

D&T is a National Curriculum subject in England, with a clear focus on teaching children how to design and make. Many school D&T departments are at least as well-equipped as a makerspace and the best meet the specification for a FabLab. This suggests an opportunity to open school D&T workshops to their communities as maker spaces. Steeg (2008) suggested this, but the response at the time was not positive, partly because, then, the idea of makerspaces was new, few had heard of FabLabs and, probably more significantly, it was hard for schools to see past the barriers of things like insurance, health and safety and site security.

In 2018 the subject of D&T is in a weakened state. High Stakes assessment structures focussed on other, traditional, subjects have reduced its status. At the same time, schools have experienced years of increasingly tight funding. In these circumstances, a subject that is expensive to run and not of the highest importance in accountability measures is an easy target for cuts. These cuts are made easier for school managements as the numbers of entrants to D&T teacher training have plummeted making it difficult to replace D&T teachers who leave. Under these circumstances, it is hard for D&T teachers explore innovations; back watching and preservation are the order of the day.

STEM (rarely STEAM), has a profile in governmental and industrial discourse about education, but it is not seen as a coherent educational strategy cutting across curriculum boundaries but rather as an umbrella term that mostly means Science and Maths and occasionally Engineering (despite the fact that this isn't, and is never likely to be, a National Curriculum subject) and is largely focused on preparation for work. D&T is almost universally absent from conversations about STEM though the case for its place has been made (Banks & Barlex, 2014). Science and Maths departments in schools have very little incentive to make links with D&T unless it can be shown this would help with their own critically important GCSE results.

### 3.2 *The potential*

Interest in introducing maker education in England exists and we believe it has the potential to enhance teaching and learning in schools. But we need to think carefully about the English context and learn from the US experience. We have seen that maker education in the US has developed common themes including constructionist understandings of how learning happens, STEM as a context and a focus on digital designing and making. Implementation has taken a number of paths which broadly are:

1. Activity outside schools.
2. Extra-curricular enhancement in schools.
3. Cross-curricular, time-tabled lessons.
4. Whole-school integration

We have also seen that in the US Technology Education has been, largely, bypassed by maker initiatives. We want to avoid the same thing happening in England, but rather encourage the development of a maker education that is respectful of maker organisations outside of formal education while standing firmly alongside D&T as the core maker subject in schools. This means we should add a fifth option to the list above:

5. Centred in D&T, but working actively across the curriculum

Depending on the strength of the D&T department in a school, this fifth option might be established via work in (ii) and (iii).

Our vision is for an approach to maker education that builds on the existing knowledge that the D&T community has about how best to support learning in and through designing and making (Barlex & Steeg, 2017) including building on our strong history of digital designing and making. D&T may need to adapt as a consequence of embracing maker education. For example, by exploring how practices might change if constructionism is taken seriously as a learning theory underpinning our work, or if a greater emphasis is placed on working with open contexts (which can only be a good thing in preparing children for the new GCSE's Contextual Challenge). Moving digital designing and making to the heart of practice (without making it the only approach) will also be required; maker education or not, the subject will need to do this anyway (or become increasingly irrelevant) as we adapt to the implications for designing and making of the third digital revolution (Gershenfeld et al, 2017). And, although the subject's experience of STEM has been discouraging, maker education is an opportunity to give D&T a strong voice within STEM, allowing the subject to (re)assert its importance in STEM initiatives (while always being careful not to be hijacked by an over-focus on 'education-for-employment').

We believe that allowing maker education to bypass D&T as it enters England will further weaken the subject, but that grasping the initiative to proactively support the development of a maker education fit for the English context could be just the restorative the subject needs. We have to be realistic about the structural weaknesses of the subject, but the first step is making the case for both maker education as a welcome and positive area of growth and for D&T's place at the heart of its development. The D&T community needs to develop a robust case for taking the lead in maker education and to start to build this case within existing relationships with national bodies, with industry, with the various strands of the English maker movement and within its own members.

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# Better making or making better: Exploring the attitudes of a school community to introducing a forge and blacksmithing into their school

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Six years ago, a blacksmith and forge were re-established in an urban, independent school. The school's philosophy follows the notion that 'learning comes from the heart' and prioritises learning 'through' activity. The previous forge closed in the 1930s. Since the new forge's introduction its use has steadily expanded, from Design and Technology through extra curricula activities to special events and to working with pupils with particular learning needs. Now the forge has achieved a certain recognition, this research explores the participant's perceptions on the craft activity of blacksmithing and the reactions of the school community. The findings were collected from semi-structured interviews with members of the school community, ranging across pupil blacksmiths, teachers, site staff, parents, school managers, and governing body. The data showed that the perceptions of the forge went well beyond a focus on skills and processes. Forge users' positive impressions were influenced by the setting, the risky activity, the unique exclusivity and the collaborative manipulating of hot metal to produce finished objects. The research reveals that the relationship that exists between the forge and the school community's ideological commitment, provides a positive extension of the school's educational philosophy in the way that it has become embedded in both curricula and extra-curricular activity. It shows how the forge embraces all aspects of the school's philosophy. It concludes that in a fertile school setting, blacksmithing adds to the engagement of the participants and the wider community, beyond simply hitting hot metal. Finally, it considers the elements necessary to replicate this, commenting that the vision of the blacksmith has to be mirrored by the school's support, both ideologically and financially, to achieve fruitful outcomes.

*Key Words: blacksmithing education, holistic development, head, hand and heart.*

## 1. INTRODUCTION

This paper reports an initial exploration of the value of housing a forge within a school. The research was conducted in an English urban, independent school, educating pupils age four to eighteen. It was founded in 1898 by a group of teachers, parents and concerned citizens. The vision was for radical, liberal, child-centred education, to counter the 'instructional' view of Victorian mainstream education, summed up by a school founder as

'the great juggernaut of modern education, the examination craze' with the over pressure on children caused by the 'medieval method of cramming with juiceless facts names and dates'. (Brooks, 1998 p.6)

The school began in a local house with one class of learners and two teachers, moving in the 1920s to a permanent wooded site where the first new building was an open shelter under a large beech tree, built and designed by the headmaster and children. This headmaster set the following objective.



To help train up its scholars in the way of the good life, to help to fit them for effective work in the world, for effective sympathy and for effective joy. (School website)

The school motto was added by a subsequent head teacher

Ex corde vita...out of the heart springs life. It is not what you put into the child, but what you draw out that constitutes education. (School website)

The initial philosophy has endured and its principles today are expressed as mutual respect, individuality and self-reliance, social responsibility, freedom, play and the enjoyment of education. The curriculum principles are represented through the ‘THRIVE compass’, a shared guide for all subjects that identifies the personal, intellectual, performance and social attributes that the curriculum fosters. (see figure 1)

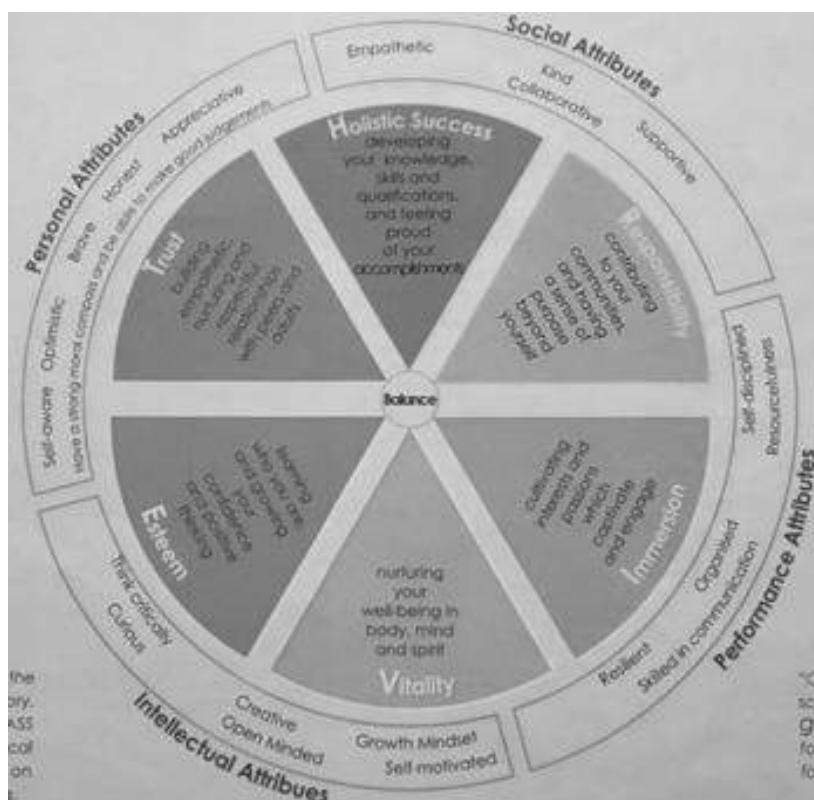


Figure 1: THRIVE compass.

Pupils’ needs for the ‘currency’ of national qualifications is balanced against the school’s philosophy and principles and its long-standing commitment to outdoor education.

The Design and Technology (D&T) Department engages with learners from age five to eighteen. The Department has a strong mission to support a spectrum of technologies: primary technologies of ‘raw’ materials and processes using ‘fundamental’ tools; secondary technologies of pre-processed materials and industrial technologies of the 20<sup>th</sup> century: and tertiary technologies, typified by digital, integrated technologies.

In the 1930s the school had a forge but it fell out of use. The current forge was introduced in 2012, created in an undeveloped wooded space behind the D&T building. It was initially seen as support for the primary technologies dimension of the D&T curriculum, but quickly became included in other aspects of the school, for example as an option in ‘Choice’ – a weekly extra-curricular activity for eleven to fifteen year olds. It has also become a place where some learners with particular individual learning needs are supported.

## 2. LITERATURE REVIEW

Blacksmithing is an ancient craft that historically was included in the forerunners of today's Technology and D&T curricula. In English schools, it was mainly taught to boys within metalwork. Currently it is rare to find a school with a forge and research into the educational value of blacksmithing is scarce. However, literature more generally on the value of craft and education has provided a helpful framework for the research reported here.

A number of researchers (Claxton, Lucas & Spencer, 2012, Illeris, 2007, Rose 2009, Alexander 2010) argue that the current English curriculum is mechanical, linear and outdated; serving an industrial society which is long-passed and committed to conformity. Robinson (2010) suggests that *'Human flourishing is not a mechanical process but an organic process; you can't predict the outcome of human development'* and consequently calls for a *'learning revolution'*. Our study is not tackling formal curriculum reform but explores how having a forge and blacksmithing within a school setting can support the curriculum in helping develop skills and attributes for children to thrive in a modern technological world.

Belief in the broad benefits of engagement in craft, including the building of character, intelligence and 'moral' behaviour', was recognised in the Sloyd education movement, established initially in Finland and Sweden in the 19<sup>th</sup> Century, that massively influenced early practical education in Europe and North America. Recently there has been a revival of interest in the value of making, including enhancing 'wellbeing' (e.g. Claxton et al., 2012; Corkhill, 2012; Marchand, 2008; Schwarz & Yair, 2010; Yair, 2011). Supported by a wealth of literature, approaches such as Forest School (O'Brien and Murray, 2006) and Outdoor Educational initiatives have become popular (Blackwell, 2015, Plymouth University, 2016). Natural England (2016) made conclusive links between children learning and making in nature being *'associated with the acquisition of academic, social and personal skills, increases in confidence and self-esteem, and improvements in physical skills'* (p.3). There are meaningful and experiential opportunities for children to learn about how the world works, science, technology, maths, communication; discrete disciplines being delivered in exciting cross-domain 'realities' (House of Commons Education and Skills Committee, 2005; Forest Research 2006). This literature supports assertions that craft activities undertaken in nature facilitates opportunities for taking risks, self-directed learning, developing motivation and concentration and social and interpersonal skills (Kinver, 2016; Natural England 2016; Play England, 2008).

A forge is a risky place and literature focuses on risk taking and how it can serve learning opportunities and development. Gill (2007) argues that taking risks in a controlled environment is a vital life skill that develops children's ability to deal with unpredictability in a quickly changing world. Play England (2008) support this view, identifying that *'the lives of children have become much more restricted and controlled over the last 30 years due to cultural, social and economic factors'* but that *'children need and want to take risks'* (p.8). Blackwell (2017) references Dweck (2000) indicating how allowing children to assess risk themselves can develop their independence, resilience, creativity and confidence. Play England (2008) differentiates between 'good playful risk' and 'bad risk'. Good risk is purposefully managed through a benefit-risk analysis where the activity facilitator judges the potential benefit of taking part in the activity versus the risk to the participants. Mortlock's Adventure Alternative (1984), aligned with Dewey's theory of experiential learning, describes four stages of 'adventure states', which helps the facilitator of an activity assess the level of risk that will enhance a child's experience and development. Mortlock (1984), Dweck (2000) and Vygotsky (1978) illustrate how much young people can achieve when given the opportunity to learn through experiences that stretch their capabilities.

A forge encapsulates many of the features identified above, providing almost primeval opportunities for making by hand. Blacksmithing is a craft practiced in an outside risky environment that provides a space where children can stretch themselves physically. But the research team questioned how much more there is to blacksmithing than just hitting metal.

### 3. METHODOLOGY

This study is a small-scale, qualitative research project, provoked by a sense that the intervention of including a forge within the D&T department had created something greater than anticipated and that understanding the space the forge had become would be valuable to the school and make a broader contribution to understanding the value of traditional crafts in current educational contexts. The research team consisted of four staff directly linked to teaching in the forge and one external researcher. Research experience within the team was varied and the role of the external researcher was largely as research mentor.

The initial stage involved the research team working together to establish overarching aims, research questions, and data collection methods. This initial work took the form of a 'mini charrette', where the team member proposing the research presented early thinking that the rest of the team critiqued, debated and extended, leading to a collective view of the focus and detail of the research.

Three overarching research questions emerged

- Is there a special/unique value that comes of having the forge in the school as perceived by the school community?
- Could the forge have been created in any school?
- Does the forge mirror the school's philosophy?

Linked to these overarching questions, a framework for a set of semi-structured interviews was created (Figure 2).

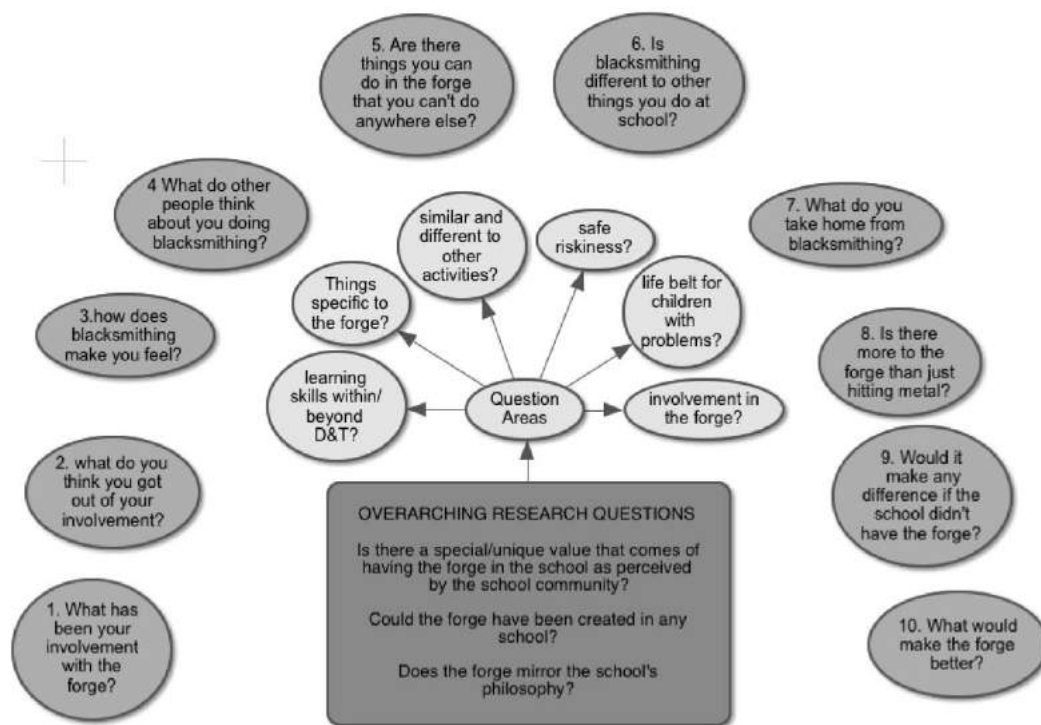


Figure 2 Framework for interview questions

A range of stakeholders were identified (D&T and Blacksmithing teachers, other teachers, professional staff, Governing Body, parents, local community). A decision was made to focus in the initial stages on a small range of adults covering school staff, parents and governors, and a small range of learners with varying ages and experiences of being in the forge. (see Table 1).

Table 1 People interviewed in initial stage of research

Stakeholder Group	Representatives
D&T /Blacksmithing staff	Retired HoD (who set the forge up) and parent
	Current HoD
	D&T teacher and Year Head
	Lower school D&T teacher (ages 5-11)
	School blacksmith 2013-2017
Other school staff	Head teacher
	Assistant Head Teacher Pastoral, and parent
	Head of Special Needs
	Head of School Facilities and parent
Governing body	Chair of Governors and parent
Learners	Upper school, long involvement with the forge through 'Choice'/Blacksmithing club/additional learning support (two girls, two boys, ages 14&15)
	Middle school, involvement through 'Choice' (3 girls, age 12)
	Lower school, involvement through lower school Blacksmithing club (2 girls, 2 boys ages 9&10)

Data analysis involved scrutinising transcripts in relation to key themes drawn from the school's philosophy and the THRIVE Compass and key contexts in which blacksmithing takes place. Additional themes were added as other aspects emerged. (Figure 3)

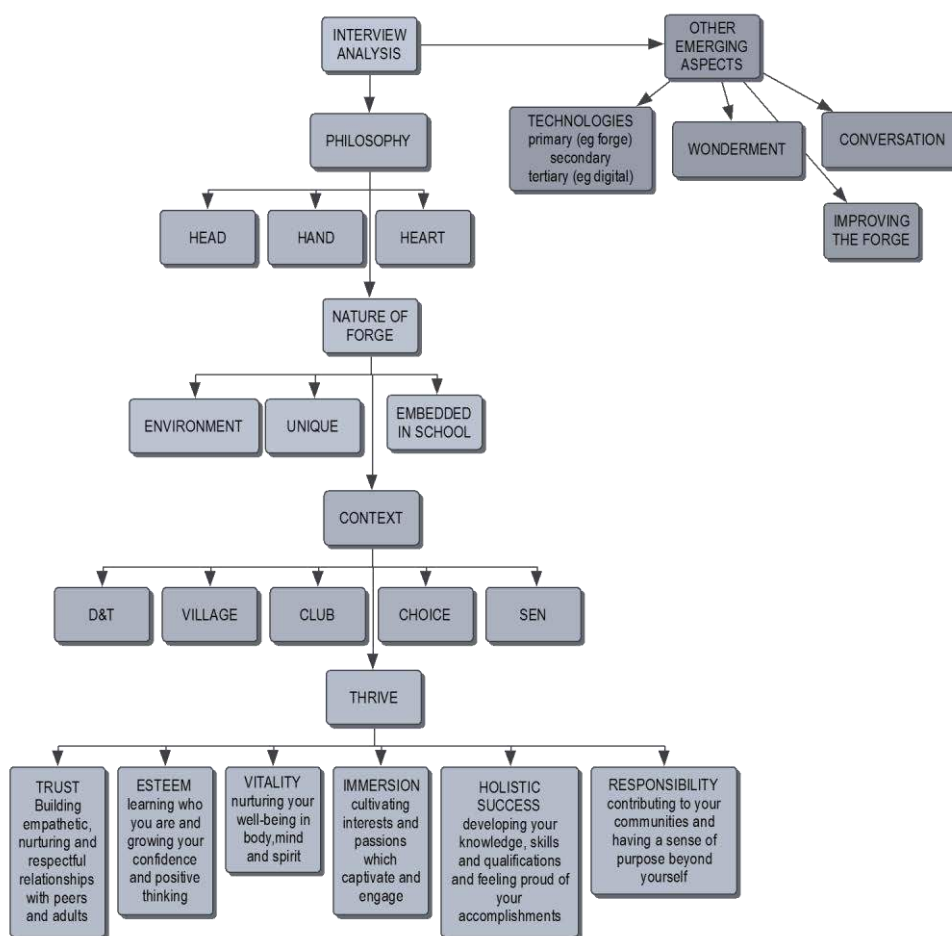


Figure 3 Structure of analysis

Annotations from the transcript analysis were then grouped thematically in order to identify perspectives and links that emerged.

## 4. FINDINGS AND DISCUSSION

This paper presents overarching findings from the early stages of transcript analysis linked to the headings of Philosophy, Nature of the forge, Context and THRIVE and more detailed discussion of two aspects of the forge that featured prominently in responses: the nature of the forge experience and the importance and value of conversation within the forge.

### 4.1. *Philosophy: Head, Hands and Heart*

All interviewees made reference to how the philosophy of ‘Head, Hand, Heart’ was embedded within both the conscious and subconscious experience of students blacksmithing. This is discussed further in 4.5.2 but it was noted that experiences in the forge allowed *‘the subconscious to come to the fore’*, *‘giving a sense of equilibrium’*. As was noted in interviews with the blacksmith and learners, these interactions were subtle, child centred and supportive. They were much valued by the learners.

Adults showed deeper metacognitive insights, making more reflective links between head, hand and heart, using descriptors such as ‘exhilaration’, ‘freedom’, ‘curious’, ‘energy’, ‘rebalancing’, ‘creativity’ and ‘nurturing’ while students mostly said it was ‘cool’, ‘amazing’ and ‘fun’. There were occasional references to pure skills acquisition (Head / Hand) but the majority of comments included emotional elements. Responses here also linked to other qualities in the developing person such as those of the THRIVE compass (fig. 1), particularly by the adults.

### 4.2 *Nature of the forge*

Findings on the forge environment can be split into the ‘physical’ (where it is and what is in it) and ‘symbolic’ (what it fosters/represents). From interview comments:

Physical: special gear, outside, messy, noisy, industrial, smoky, fairy lights, allowed to get near to the fire, heat, manipulating metal, done in small groups, beehives next to it, a part of school but separate from it.

Symbolic: independent but ‘held’, safe but dangerous, excitement, creative, freer, less ‘teacherly’, treated like adults, fearless and intuitive, a space to think and grow, non-judgemental, learning about themselves

Strong links were made between the environment fostering qualities such as ‘trust’ and ‘responsibility’ and that the environment encouraged meaningful ‘conversation’ (see 4.5.2). Adults gave more metacognitively advanced responses relating the environment to *‘alchemy’* and *‘mystery’*, an *‘old fashioned’* setting having elemental qualities that appealed to more basic primitive elements of humans in their responses to fire and work. Students gave more straightforward responses, talking about *‘a cool space to meet friends’* and *‘magical’* though it was clear they liked the links between risky-safe space, a non-teacherly environment and being treated like adults.

Interviewees also all said the forge was unique in some ways, being in an urban school, the nature of its environment, its approach being *‘admirable’* and *‘surprising’* creating strong relationships - both peer-to-peer and teacher-pupil. Uniqueness was also seen in the way it fostered a special community.

“it’s a community ... not just the people who come to club it’s the whole department ... students from A level, GCSE trickling in ... Wednesday and Friday afternoons or any afternoon and ... I’ve found a sort of hodge podge little family.” (Upper School pupil)

### 4.3 *The context of the activities*

There was evidence that the forge and its activities were known and valued by all those interviewed. What went on in the forge was seen to fulfil needs within the D&T curriculum, the Choice (extra-curricular) programme, after-school clubs, the ‘Village Project’, cross-curricular experiences and additional learning support. The forge

was seen as an educational resource, having a special value in giving a different 'life' to other subjects. Notably, the forge was seen by school management as embodying the fundamental philosophies of the school, delivered in an innovative and high profile way.

#### **4.4 The THRIVE Compass**

Through all the interviews links were made to how the forge promoted and fostered all outcomes of THRIVE, both individually and in more integrated ways. Several comments highlighted how the potentially confrontational environment and high-risk activities supported behaviour that THRIVE defines.

"you've seen the wheel and the flourish [THRIVE] thing, this idea that our education touches all of these parts and it aims to ... the forge is ... it's a sort of a practical skill, it provides some kind of emotional nourishment. It also provides an education thinking about how to design something ... you're learning, you're using your brain, but it also has this really strong nurturing element, so for me it's incredibly innovative." (Chair of Governors & Parent)

While each element of the compass was evidenced, Esteem, Responsibility and Trust were particularly identified in transcripts, including in interviews with pastoral and special educational needs staff and pupils experiencing challenges in their lives. Time spent in the forge improved self-image and self-esteem, which impacted positively on other aspects of their lives.

"It was a very difficult point in my life and the forge was kind of the place where I could release that stress." (Upper School pupil)

"the forge enables kids to come together as individuals and create a different kind of group ... there are different rules ... it's purely creative, there is a notion of health and safety so it's not like some free play, so it needs to be respectful ... it's encouraging them to take on independence, being critical ... and really working with other people" (Head of Special Needs)

Pupils identified the forge as 'their safe space' in which they could operate with more autonomy and confidence.

#### **4.5 The Nature of the experience and the value of conversation**

All interviewees perceive the forge as a different place, outdoors and separate from the school, initially confronting, dirty, untidy, smoky and with a fierce fire at its centre. Special clothes are required. The activity is seen as somewhat primitive and having a sense of the historical, magical, mystical and subliminal. Blacksmithing is seen as essentially a craft and design activity where skills and knowledge of creativity and manipulating iron are learnt and practiced. It is seen as both simple and complicated. Getting the metal hot and hitting it is not easy, but attainable to all. The feeling of changing dangerous hot metal is pleasurable, liberating and creative. With its violent level of physical activity, the forge is seen as a very different place in city children's lives. Sessions often end with tea and toast or toasted marshmallows, made on the fire embers with self-fabricated toasting forks, accompanied by reflective chatting. At the end participants have physical evidence of the hard work to take home with them.

The younger pupils see the forge experience as safe but risky and fun. Older, more experienced pupils were able to reflect and say what the forge had done for them as people. Adults who had done some forging were more able to comment on the emotional and personally valuable qualities of the experience as opposed to those who had just watched whose comments were no less perceptive but less effusive.

One of the 'special' qualities of the forge experience was the value of the opportunities it provided for sharing of thoughts and experiences. Using the forge was recognised as being collaborative, requiring communication, conversation and discussion. The waiting time of getting metal hot and the action of hitting it enforced a rhythmic activity, giving space for discussions about the work or about the outside world.

"The distinctive thing about blacksmithing is that you only work for a couple of minutes at a time, then you wait. You have to plunge your metal into the fire and wait for it to heat up. I have a feeling that it's during the waiting time that most of the talking happens. So, it's this rhythm of work - wait - work - wait. ... there does seem to be something important, in this rhythmic and possibly symbolic activity, about the quality of the relationship between the blacksmith and the student. (retired Head of D&T)

The 'choreography' of the rhythm of the forging activity, the release of tension through the violent effort of forging, the collaborative relationships of working together and building trust all seemed to make talking easier.

#### **4.6 Making the forge better**

How to make the forge better caused something of a dilemma. Some pupil's comments indicated that they were happy that it was a fringe, minority activity in a place they could identify with - their 'secret space' for them and their friends. Some, particularly the youngest pupils, said it should be more universal and part of a wider range of D&T and whole school experience. Adults expressed the same dilemma, concerned to expand the sphere of influence without destroying the 'specialness' of the forge experience. Some commented on how increased public awareness of what having a forge did for the image and ideals of the school, had a positive effect on parents and prospective pupils.

### **5. CONCLUSION AND NEXT STEPS**

Reflecting on the research questions, this research is indicating that the forge does have special and unique value in the school and there is evidence that it mirrors the school's philosophy. What is significant is the sphere of influence that has been made possible by the collaborations of the blacksmiths within and beyond the D&T department, resulting in its value being identified more widely by staff, parents and governors. Together they have produced a unique and special thing. Together the school has influenced the forge as the forge has influenced the school.

Rather than answer whether this could be done in any school it is probably more useful to distil the elements that need to be in place for a similar experience to be provided elsewhere. The vision that a blacksmith brings to the activity has to be mirrored by the desire of the school to support a forge, both ideologically and financially for there to be a fruitful outcome. This is a potential area for exploring as the study is extended, alongside research possibilities for areas such as gender, accreditation and the relationship between blacksmithing and wellbeing.

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# Learning to weld in technical vocational education: the first cycle of an action-oriented study

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Creating efficient learning environments where students learn what they are supposed to learn, as well as understanding the relations between teaching and learning are recurring issues in educational settings. The importance of studying these issues in school practices is highlighted in different studies, but in relation to technical objects of learning in vocational education, there is an evident lack of such studies. By implementing an action-oriented study in iterative cycles, inspired by the Learning Study method, this study aims to redress this lack by focusing on learning processes involved when a vocational teacher and upper secondary students interact with tools and materials in relation to the object of learning to weld. We combine two different perspectives in the project (cf. Asplund & Kilbrink, 2018); variation theory analysis (VTA) (cf. Bjurulf, 2008; Marton & Tsui, 2004) and conversation analysis (CA) (Schegloff, 2007; Sidnell & Stivers, 2014). The study will be conducted as a collaborative project between a vocational teacher and two university based researchers and is funded by The Swedish Institute for Educational Research. During spring 2018 we will conduct the first cycle of the study and at the conference we will present this ongoing project and data from the first cycle.

*Key Words: Action research, Conversation analysis, Technical vocational education, Variation theory, Vocational learning.*

## 1. INTRODUCTION

Recently, the demand on collaborative research in actual school setting has been raised to develop and implement teaching on a scientific basis at school. The use of research-based methods in practice-centred school research is emphasised as an important part of improving teaching and learning at school (cf. Carlgren, 2017; Skolforskningsinstitutet, 2018). Furthermore, creating efficient learning environments where students learn what they are supposed to learn, as well as understanding the relations between teaching and learning are recurring issues in educational settings. The importance of studying these issues in school practices is also highlighted in different studies, but in relation to technical objects of learning in vocational education, there is an evident lack of such studies. Still, it is rare that studies on collaboration between teachers and researchers are made in this specific area (cf. Kilbrink, 2018; von Schantz Lundgren et al., 2013). In a previous study on welding in technical vocational education we saw the possibility to understand the process of vocational learning in relation to the specific object of learning (OoL) to weld by using methods based on variation theory (cf. Bjurulf, 2008; Marton & Tsui, 2004) and conversation analysis (CA) (Schegloff, 2007; Sidnell & Stivers, 2014) to reach both the what- and how-aspects of learning (Asplund & Kilbrink, 2018; Kilbrink & Asplund, 2016). Therefore, we aim to take this research one step further and implement an action oriented study in collaboration with a vocational teacher, based on these two theories, and the study presented in this paper is the result of the initiated process with this work. More precisely, the aim of this paper is to examine the experiences and results of the first cycle (of a total of 9) of an action-oriented study focusing on learning processes involved when a vocational teacher and upper secondary students interact with tools and materials in relation to the OoL to weld.

## 2. LITERATURE REVIEW

Learning in technical as well as vocational education is considered as something specific in previous studies. Handicraft, practical experience and the bodily aspect of learning are highlighted as typical for this type of learning (cf. Bjurulf, 2008; Björkholm, 2015; Kilbrink, 2018; von Schantz Lundgren et al., 2013). However, there are few studies investigating learning of specific learning content in these areas and research pinpoints a need for how teaching and learning of different content is done in relation to technical objects of learning (cf. Asplund & Kilbrink, 2018; Hallström, 2018; Kilbrink, 2018). There are even fewer studies focusing on this area in practical settings, hence the need for studying technical objects of learning in actual teaching. Studies on how different learning contents are taught has been made previously using the Learning study method in collaboration between teachers and researchers, aiming to bridge the theory – practice divide between research and teaching in practice (cf. Kilbrink et al. 2014; Lo, 2009). Learning study is a form of action research with a specific focus on the learning content and is normally based on the variation theory of learning. Variation theory pays specific attention to the content of learning, described as the OoL. There are only a few Learning studies in the area of technology education (Björkholm, 2015; Kilbrink et al. 2014) and the area of vocational education (von Schantz Lundgren et al., 2013).

In vocational education, objects of learning are often taught in interaction between teacher and learner. For that reason, the strict focus on the learning content, without taking into account the aspect of how learning is done in interaction, is too narrow in order to understand the process of learning (Asplund & Kilbrink, 2018). In order to reach both the what- and the how-aspects of learning, we combine a variation theory perspective with a conversation analytic approach to learning in interaction (cf. Emanuelsson & Sahlström, 2008). Hence, this action-oriented study is inspired by the learning study method, but adapted to the context and the two theories in use (see below).

Currently, there is a growing number of CA studies on learning, and the majority of these studies argue that CA's understanding of participation and social organisation can contribute to a better understanding of learning in interaction (Gardner, 2012; Lee, 2010; Sahlström, 2011). Recently, many researchers have been interested in further studying issues of content from a CA point of view, by showing how learning is something that is established in interaction, and how issues of content can be integrated in the analysis of interaction (Melander, 2012a, 2012b; Melander & Sahlström, 2009a, 2009b; Sahlström, 2012). Research studies combining CA with other theoretical perspectives in order to clarify the content being taught and towards which participants orient in interaction have been done before (Asplund & Pérez Prieto, 2013; Asplund & Kilbrink, 2018; Emanuelsson & Sahlström, 2008), although to a small extent, and our research should be seen as a continuation of this research.

## 3. METHODOLOGY

As described above, we implement an action-oriented study by focusing on learning processes involved when a vocational teacher and upper secondary students interact with tools and materials in relation to the OoL to weld. We combine two different perspectives in the project (cf. Asplund & Kilbrink, 2018); variation theory (cf. Bjurulf, 2008; Marton & Tsui, 2004) and conversation analysis (CA) (Schegloff, 2007; Sidnell & Stivers, 2014). The study will be conducted as a collaborative project between a vocational teacher and two university based researchers. During spring 2018 we have conducted the first cycle of the study and in this article we present this ongoing project and data from the first cycle.

### 3.1. Action-Oriented Study

This study is described as an action-oriented study while it is conducted in collaboration between two researchers and a vocational teacher at an upper secondary school, and the teaching is planned and analysed by using the two theories mentioned above. The teaching will be planned, implemented and analysed in iterative cycles, inspired by the Learning study method (cf. Kilbrink et al., 2014; Pang & Ling, 2012). In a Learning study, there is a specific focus on the learning content (referred to as the OoL), and the use of variation theory. The teaching of this OoL is planned and analysed in specific steps in iterative cycles; pre-test, planning, teaching, post-test, analyse and revise. In our study, however, we have removed the pre- and post-test, and instead added a CA approach in order to analyse how welding competences are displayed, developed and

learned in the social interaction. Approaching the data from a CA's understanding of participation and social organisation can help us to reveal the learning processes that take place in the interaction from an emic perspective (see a further description of this below). The CA perspective can also add another aspect of how the OoL can be varied in interaction using different semiotic resources (cf. Asplund & Kilbrink, 2018).

### **3.2. VTA**

Variation theory is a learning theory which emphasises the learning content as the OoL (cf. Marton och Tsui, 2004). The OoL can be divided into the intended OoL (what the teacher planned for), the enacted OoL (what was possible to learn in the teaching/learning situation), and the lived OoL (what the students actually learned). Aspects of the OoL that are important to know in order to know an OoL are called critical aspects. For example – in order to know that a triangle is a triangle, you need to know that it has three angles and three sides, which makes the angles and the sides critical aspects. Those critical aspects can vary. For example, a triangle can be a right angle triangle or not, but is still a triangle. If the figure has four sides instead, it is no longer a triangle. This variation can be described in patterns of variation, which has been described as necessary conditions for learning. In order to see something, the critical aspects of this something also need to be discerned by the learner. The first example – when comparing different kinds of triangles, generalisation as pattern of variation is used, while the pattern of variation used when comparing three sides to four sides is contrast. When separating one critical aspect at the time, the pattern is called separation and when comparing all the critical aspects at one time the pattern of variation fusion is used (cf. Marton & Tsui, 2004). Furthermore, fusion can relate to how the critical aspects of the OoL interrelate (internal horizon of fusion) or to how the OoL as a whole relates to the context (external horizon of fusion) (Lo and Chik, 2016).

In the study we use the variation theory together with CA as a basis for the teaching, and as a tool for analysing the teaching and learning. We use the concept variation theory analysis (VTA) for this analytical tool. The focus in the VTA is on what patterns of variation appear in the actual teaching situation – in the interaction between teacher and student in relation to the enacted OoL, where the CA can help us with a close and detailed analysis of the interaction itself (cf. Asplund and Kilbrink, 2018).

### **3.3. CA**

In our study, we view learning as situated in social situations and contexts, where participants, in our case a teacher and his students, are engaged in mutual social actions (e.g. Enfield and Levinson, 2006; Lave, 1993; Sahlström, 2011). We use the methodological tools provided by conversation analysis in order to analyse and describe how aspects of teaching and learning evolve through the participants' orientations in the situated activity of learning how to weld. In our analysis, we understand both verbal and non-verbal language as resources that people use to produce and reproduce social reality; thus not only speech but also other semiotic resources such as body movements and physical objects are seen as constitutive of the activities being analysed in our study (Goodwin, 2000). In line with the CA strive for an emic perspective on both data construction and analysis, our analysis focus on how the participants understand the situations, there and then, and how they orient to these situations (e.g. Lee 2010; Melander 2012b; Rusk, Pörn, Sahlström & Slotte-Lüttge, 2015). This means that we examine which actions are made relevant at a specific moment in the interaction, and how they are made relevant, from the participants' point of views, and the method involves the use of the participants' demonstrated understanding of each other's actions, and thereby provides material for analytic explication (Schegloff, 2007). In doing so, video recordings are transcribed in great detail according to specific conventions (e.g. Mondada 2006).

Our approach is thus in line with the content-centered CA-studies that aim to capture interactional practices linked to learning a specific content or practice (see Rusk et al., 2015). This means that our focus is on how the teacher and the students orient to the specific OoL of how to weld, and how the teacher and students adapt and change their participation in the unfolding interaction regarding how to weld, where the VTA can help us understand the enacted OoL in detail.

### **3.4. Implementation of the first cycle**

Before implementing the first cycle, the teacher read our previous research on welding (Asplund & Kilbrink, 2018) and a text on variation theory (Carlgren, 2017). Thereafter, the cycle started with an interview conversation with the vocational teacher, conducted by the two researchers. The overall purpose of this

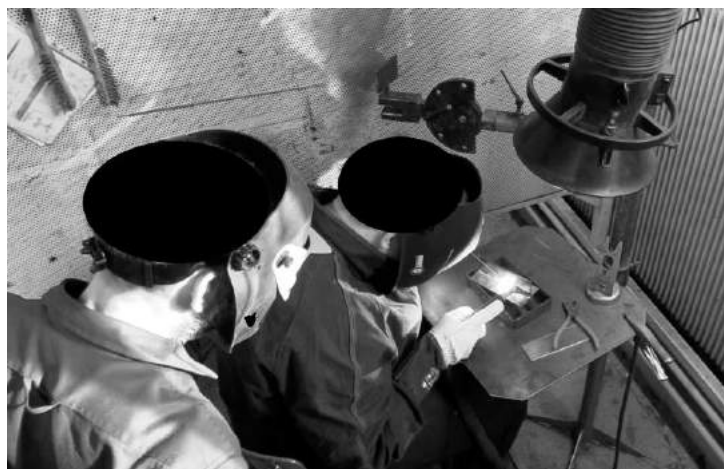
conversation was to give the researchers some insights into the vocational teacher's didactic approach to the teaching of the specific welding method (TIG welding) that was going to be conducted and video filmed during the first cycle lesson. Another purpose with the interview conversation was to give the researchers insight into the specific teaching context. During this conversation, the teacher also described the main/most central features of the welding method TIG and reflected on the challenges students have to deal with when learning to weld TIG, based on his previous experiences of teaching this welding method. Based on this conversation the researchers identified some possible critical aspects of TIG-welding. However, for this first cycle, we did not go into planning these critical aspects in detail using the CA and VTA, but rather asked the teacher to teach as he was used to (possibly influenced by the texts he had read through).

Two weeks after this conversation, the researchers visited the participating school and informed the teachers in the working team, the school principal and the focus students chosen by the teachers to participate in the first cycle of the project. Everyone was positive about the project and all four students agreed to participate. The week after that, the first cycle lesson was conducted and the teaching was videotaped. The video recordings were analysed by the researchers at a primary stage, then analysed by the researchers and the teaching vocational teacher together. Three students participated in this lesson (one was absent). Based on these analyses, based primarily on a variation theory analysis and conversation analytic perspective, the teacher, together with the researchers, has worked on new teaching strategies that are to be incorporated into the teacher's didactic approach towards cycle 2.

#### 4. RESULTS

The first cycle started with an interview conversation between the researchers and the teacher. The possible critical aspects of TIG welding that emerged during this interview conversation with the teacher concerned aspects from seeing the melt and handling the tools, to ergonomics and cleaning. This means that we could expect a very broad area of teaching with regards to how to weld in the actual first cycle lesson, which was also the case. The video recorded lesson in the first cycle lasted for two hours. The class started with a teacher led introduction lasting for about 70 minutes. During the introduction the teacher raised a plurality of aspects, relevant for learning to weld TIG welding. This also meant that there were many different OoL in relation to TIG-welding present in the introduction, also concerning the variety of aspects that emerged from the introducing conversation with the teacher. The teacher's introduction then ended with the teacher instructing how to weld TIG, and the students were asked to stand behind the teacher one by one to watch him weld. Hence, the results show that there are many aspects of welding in the introductory session.

After the instruction and demonstration made by the teacher, the students got some time to weld on their own, where the teacher alternated supervision of the different students in their welding booths (see Figure 1).



*Figure 1. Teacher and student involved in welding*

In this phase we interpret the OoL to be narrowed down to the actual making of a TIG-weld. This OoL (the making of a TIG-weld) is also our focus in the analysis of the interaction between the teacher and the students.

In our analysis we can see that some critical aspects emerge in the interaction in relation to the enacted OoL. Those critical aspects are oriented to and made relevant by the students, and the teacher, in the interaction. This means that the critical aspects that emerge when the teacher interacts with the different students are not identical. Thus, they differ between the students, but can be summarized as:

- The melt (the most central aspect)
- Welding mode (weight drop and how the melt flows in relation to welding mode, as here, position B)
- The material welded on
- The additive material
- The movement
- The speed of welding
- The body position
- The current (amperage)
- The distance to the welding material
- The substrate welded on

During the lesson, the teacher was using different gestures and patterns of variation (generalisation and contrasting) to emphasise those critical aspects that were oriented to in the interaction (cf. Asplund & Kilbrink, 2018). One example of teacher and student interaction can be seen in Figure 2 below.

1. ((the teacher grabs the student's right shoulder  
 2. and squeezes it))  
 3. Student: but I don't know how I hold. I don't actually know  
 4. how I should hold  
 5. Teacher: it is like I said, find yourself a: ( . ) keep  
 6. searching for your way forward  
 7. some ho::ld ((leans forward and grabs the welding  
 8. tool))the burner like this:



9. Student: mm: ((nods))  
 10. Teacher: some use a pen hold ( . ) that is you take it  
 11. like this



12. Student: ((nods. looks at the teacher))  
 13. Teacher: and for those of you who are right-handed it is like  
 14. ( . ) this you know instead



15. Student: ((nods))

Figure 2. Teacher and student interaction

One time the teacher asked the students to take a break and gather outside the welding booths for a short common briefing, but this break was not related to the narrowed OoL, but to the welding material and how to handle this in order to save costs. Hence, there was an alternation between internal and external aspects of the OoL as well as between internal and external horizon of fusion (Lo & Chik, 2016). The teaching shifted between focusing on the wholeness and the details – from whole to parts and vice versa.

Based on the analysis we made after the first cycle, we aim to focus on the narrowed OoL – the actual making of a TIG-weld and to include the VTA and CA theories in the planning of the second cycle together with the teacher. Thereby we hope to reach a more detailed understanding of the process of learning a specific technical vocational content in interaction.

In our first preliminary analysis we can see that there is a clear orientation towards the activities as teaching and learning activities. By using CA methodology we can validate our claims based on what the participants orient to and make relevant in the interaction here and now. This means that we can also see processes of explicit longitudinal orientations. In these examples, both the teacher and the students, orientate not only towards the welding that takes place here and now, but also towards the welding that has been done, and the welding that shall take place next. This content-integrated longitudinal orientation is one aspect that makes it possible for us to describe the studied situations as learning situations (Sahlström, 2011), and make claims about the learning processes that take place.

## 5. DISCUSSION

Already after the first cycle in this project, we can find many different results that can be studied further to get a broader knowledge on both the teaching of the object of learning to weld and of this way of working with an action-oriented approach in collaboration between teachers and researchers in relation to specific objects of learning in teaching. These results could assist in understanding the OoL in more depth and finding concepts and words for what teachers and students do in the actual learning interaction of the OoL. Thereby, this research can contribute to teachers' professional learning and in the longer run also to improving teaching and learning.

## 6. ACKNOWLEDGEMENTS

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# Reconceptualising PCK Research in D&T Education: Proposing a Methodological Framework

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Since first conceived, the concept of pedagogical content knowledge (PCK) has attracted much attention. Despite being lauded by educationalists as the unique knowledge base of teachers, research on the concept over the past 30 years has yet to result in a universally accepted definition being presented. Much of the contentions surrounding the lack of an agreed upon conception appear to have stemmed from difficulties in understanding the relationship between PCK, other areas of teacher knowledge, teacher beliefs, and enacted practice. This paper considers the application of PCK frameworks to design and technology (D&T) education through an analysis of the nature of the discipline from an ontological and epistemological perspective and contemporary perspectives on the construct of PCK. It is theorised that the volition afforded to teachers in D&T through weakly framed subject boundaries negates the effective application of PCK frameworks as teachers' beliefs have a greater impact on enacted practices. In an attempt to better understand enacted practice in D&T education, the paper proposes a methodological framework centred on the interactions between teachers' beliefs and knowledge in the discipline. Through synthesising the concept of amplifiers and filters of practice with the nature of D&T education, the proposed framework outlines the need to recognise individual teachers' conception of capability as a critical influence on enacted practice.

*Key Words: Enacted practice, Pedagogical content knowledge, Teacher beliefs, Amplifiers and filters of practice, Design and technology education.*

## 1. INTRODUCTION

The promise of a concept with the potential to represent expertise in teaching (Abell, 2008) and aid in explaining enacted practices (Park & Oliver, 2008) has resulted in many calls for Pedagogical Content Knowledge (PCK) research in design and technology (D&T) education (de Vries, 2003, 2015; Engelbrecht & Ankiewicz, 2016; Jones, Bunting, & De Vries, 2013; Mioduser, 2015; Ritz & Martin, 2012). Despite efforts to theoretically conceptualise a model for enactment of PCK (Jones & Moreland, 2003, 2004), and applied approaches to measuring the construct through multiple choice questionnaires (Rohaani, Taconis, & Jochems, 2009, 2012), PCK research in D&T remains largely underdeveloped when compared to other disciplines. Williams, Lockley, and Mangan (2016) suggest that the degree of international diversity regarding the content of D&T may have served as an impediment to the consistent development of research in the area as the implicit nature of knowledge employed in D&T activity (Kimbell, 2011; Williams, 2009) is theorised to have a significant impact on how teachers access and use their knowledge.



In an attempt to better understand enacted practice in D&T education this article considers contemporary research on PCK, subsequently presenting a methodological framework to represent the relationship between teachers' beliefs, knowledge, and enacted practice. However, it is important to first explore D&T education from an ontological perspective and discuss how contemporary understandings of the nature of D&T distinguish it from other disciplines.

## **2. DISCIPLINARY CONSIDERATIONS**

Unlike many other areas on the curriculum, defining specific content knowledge for study in D&T has proven difficult as the classical philosophical notion of knowledge as justified true belief does not necessarily apply to technological knowledge (de Vries, 2016). Norström (2014) suggests that the main reason for this stems from technological knowledge's inherent action orientation as the discipline is less concerned with whether knowledge is true or not, as it is instead focused on whether the knowledge is successful in guiding actions towards certain goals. As a result of this, disciplinary goals are often described at a conceptual level, such as technological capability or technological literacy. Although these terms were initially conceived as separate entities, where technological literacy was concerned with the understanding and use of technology, and capability as one potential to operate as a design and technologist (Kimbell & Stables, 2007), more recently, definitions of the terms have begun to converge. Contemporary depictions of technological capability and literacy (Dakers, 2014; Ropohl, Nielsen, Olley, Rönnebeck, & Stables, 2018; Williams, 2009) highlight that educational goals in the discipline are not exclusively knowledge based and that there are a variety of problem-solving aptitudes, value-oriented perspectives, as well as manipulative skills that are necessary to be considered technologically capable or literate.

From a pedagogical perspective, the autonomy afforded through a discipline bereft of explicitly defined content knowledge may be viewed as a unique advantage of D&T education, in that ownership lies with the teacher, who can in turn draw upon their own interests, their students' interests, and recent developments in the field to engage learners with relevant concepts when required (Spendlove, 2012). If there is consensus between the goals of D&T as espoused in curricula and the beliefs implicitly held by teachers, then this is true. On the other hand, the variability in practices afforded through autonomy of this nature may be problematic as teachers' implicit conceptions of what is of importance to student learning may have a greater influence on the nature of activity students engage with, particularly if these implicitly held conceptions do not align with intended learning outcomes. Therefore, in D&T education understanding teachers' implicitly held beliefs about the nature of D&T and the nature of activity in D&T is of interest in understanding enacted practices.

## **3. CONTEMPORARY UNDERSTANDINGS OF PCK**

Since its inception, a significant proportion of PCK research has been devoted to either explorations of the construct from theoretical perspectives or the representation of teachers' PCK relative to a selected theoretical conceptualisation. However, over the past number of years, debates about the relevance of these approaches have emerged (Kind, 2009, 2015). Central to the concerns raised is an apparent disjunction between PCK research and understandings of enacted practice, a trend that has seen researchers call for PCK research that is more predictive of enacted practice (Abd-El-Khalick, 2006). With this, concerns pertaining to the nature of PCK are often related to the foundational or applied methods by which PCK has been studied, as many of the methods developed have undergone scrutiny; either due to their inability to capture PCK in an ecologically valid manner; or criticisms have been founded on a lack of topic-specificity in the instrument design. This culminates in the capture of both pedagogical and content knowledge (as well as several other professional knowledge bases), however, the intricacies of PCK are often believed to have been misinterpreted (Friedrichsen, van Driel, & Abell, 2010) or not captured at all (Kirschner, Taylor, Rollnick, Borowski, & Mavhunga, 2015). Further to this, the difficulties in validly and reliably capturing PCK appear to have stemmed from the assertions that PCK is topic-specific (Mavhunga, 2012).

In an effort to synthesise understandings of the concept of PCK and address the emerging contentions presented above, attendees at the summit on PCK research in science education (BSCS, 2012) developed the consensus model of teacher professional knowledge and skill (Gess-Newsome & Carlson, 2013). The model (Figure 1)

categorises three different types of teacher knowledge; teacher professional knowledge bases (TPKB), topic-specific professional knowledge (TSPK), and PCK. TPKB are defined as general (not content specific) knowledge bases for teaching, such as knowledge of assessment or general pedagogical knowledge. As knowledge bases, these are normative and can be used to construct assessments to quantify what teachers know. TSPK, on the other hand, is knowledge that has been codified by experts in a discipline and is recognised as being important to student learning; a public understanding held by a teaching community. Gess-Newsome (2015) asserts that an example of this type of knowledge would be the a Content Representation (CoRe) as the CoRe instruments represents how a community of teachers think about how to teach a particular topic to a particular grade level (for more information on the nature and application of a CoRe see Loughran, Berry, & Mulhall, 2006). In contrast to TPKB and TSPK, which are held between groups of teachers at a topic or professional level, PCK is recognised as personal knowledge held by individual teachers. Attendees at the summit define PCK as “the knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes” (Gess-Newsome, 2015, p. 36).

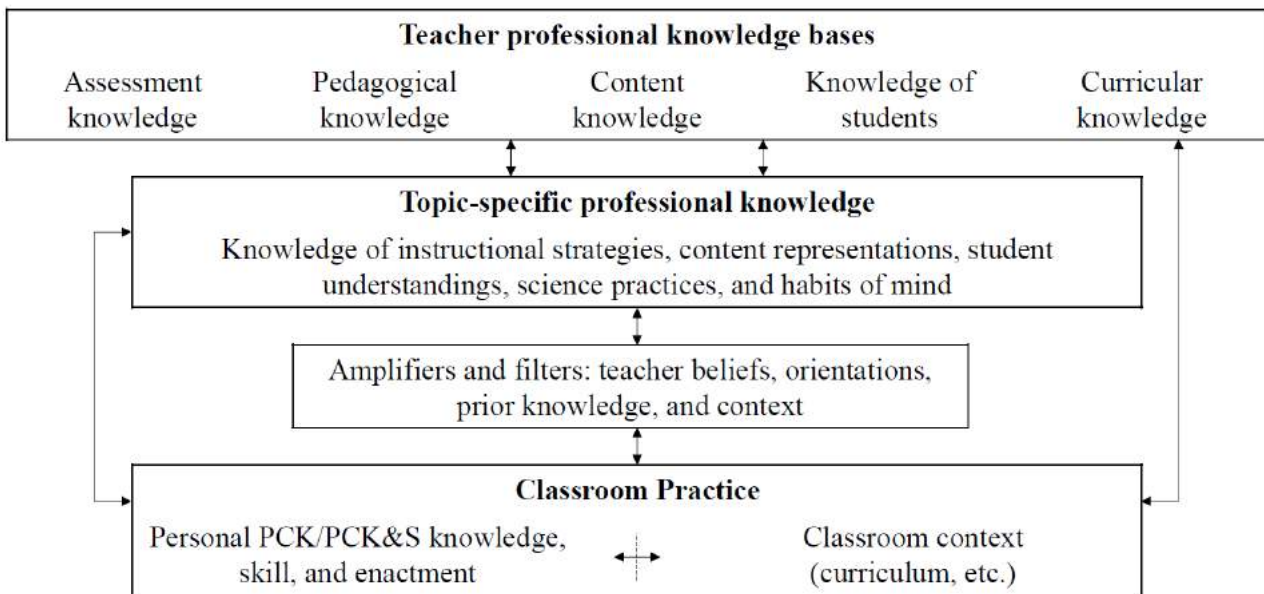


Figure 1. Model of teacher professional knowledge and skill including PCK (Gess-Newsome & Carlson, 2013).

#### 4. PCK, TEACHERS’ BELIEFS AND ENACTED PRACTICE

Despite the initial conceptualisations of PCK considering the concept as exclusively a knowledge base (Shulman, 1987), the consistent re-emergence of PCK models containing constructs related to teachers’ beliefs (Anderson & Smith, 1987; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Park & Chen, 2012) suggest the importance of this construct in influencing teachers’ practices. Referring to teachers’ beliefs about the purposes and goals of teaching a subject, constructs related to teachers’ beliefs are perceived as being influential due to their regulatory relationship between teachers’ knowledge bases and PCK. Magnusson, Krajcik, and Borko (1999) indicate that teachers’ beliefs serve as the “conceptual map” (p. 97) that guide instructional decisions about issues such as daily objectives, the content of student assignments, the use of textbooks and other curricular materials, and the evaluation of student learning (Borko & Putnam, 1996). However, similar to research on the nature of PCK, research exploring teachers’ beliefs has been marred by different conceptualisations of the position of beliefs relative to PCK and enacted practice. In an effort to synthesise current understandings of the terms, Friedrichsen et al. (2010) conducted a literature review of uses of the term orientation in the PCK research community. In their paper, they highlighted four methodological issues with the use of the term: (a) using orientations in different or unclear ways, (b) unclear or absent relationship between orientations and other PCK model components, (c) simply assigning teachers to one of the nine categories of orientations theorised by Magnusson et al. (1999), and (d) ignoring the overarching orientations component. In an effort to progress the orientations agenda, Friedrichsen et al. (2010) summarised

their review in presenting a model for future research in science education. The presentation of the model was perceived as the first stage in developing conceptual and methodological clarity regarding orientations.

In introducing the model of teacher professional knowledge and skill (Figure 1), Gess-Newsome (2015) detailed that the knowledge held in both the TPKB and TSPK components of the model are commonly held by teachers in the profession, and although this knowledge is accessed by individual teachers in order for it to be personalised, “it must pass through the lens of the teacher” (Gess-Newsome, 2015, p. 34). The autonomy afforded to teachers in their selection and implementation of pedagogical approaches is described as being mediated by teachers’ beliefs and orientations. Situating beliefs in the intermediary between teachers’ knowledge bases and enacted practices, or as an amplifier or filter of practice, affords the opportunity to better understand enacted practices as this organisation of teacher knowledge is cognisant that teachers’ beliefs have the potential to affect practice in a variety of ways.

## **5. RECONCEPTUALISING PCK RESEARCH IN D&T**

In considering the application of PCK frameworks to D&T education, several contentions emerge. Paramount amongst these contentions is the nature of activity in D&T, as the volition afforded by loosely classified and loosely framed knowledge boundaries facilitates educational agendas that are specific to individual teachers. This freedom has been framed as a unique advantage of the discipline (Spendlove, 2012) and although the conceptually focused composition of D&T curriculum will allow D&T teachers’ beliefs to have a greater influence on enacted practice, a significant challenge emerges if individual teachers’ educational agendas are not aligned with the outcomes prescribed in D&T curricula. In light of this, the following section presents a methodological framework to explore the relationship between teachers’ knowledge, teachers’ beliefs, and amplifiers and filters of enacted practice in D&T education.

In acknowledging Settlages’ critique of PCK as traditionally being bound to its knowledge-as-commodity construct and the relatively little regard given to what teachers actually do (2013), the authors propose that a model concerned with better understanding enacted practice must centre on exploring enacted practice, while remaining cognisant of both teachers’ knowledge and beliefs. In contrast to the model developed at the PCK summit (Figure 1), it is theorised that D&T teachers’ beliefs will have a greater influence than the mediation between teachers’ knowledge bases and enacted practice. In particular when considering the nature of D&T education as presented earlier, the freedom afforded to teachers is increased through the lack of a commonly agreed upon epistemology in the discipline. In other words, before a teacher’s knowledge in D&T is mediated by how to teach and why, they must decide what to teach. The framework proposed by Friedrichsen et al. (2010) is perceived to be of particular use here as it not only considers pedagogical and epistemological elements of teachers’ beliefs but also their ontological beliefs specific to the nature of the subject. The theoretical model presented in Figure 2 helps to represent the interactions that occur between teachers’ beliefs and knowledge in D&T education, and the centrality of enacted practice. The framework synthesises the three knowledge bases proposed at the PCK summit (Gess-Newsome, 2015) with the orientations framework proposed by Friedrichsen et al. (2010). Critically, as opposed to being a model of PCK, the researchers view this as a model of enacted practice in D&T and utilise the concept of PCK for its explanatory power in depicting the intricacies of everyday practice.

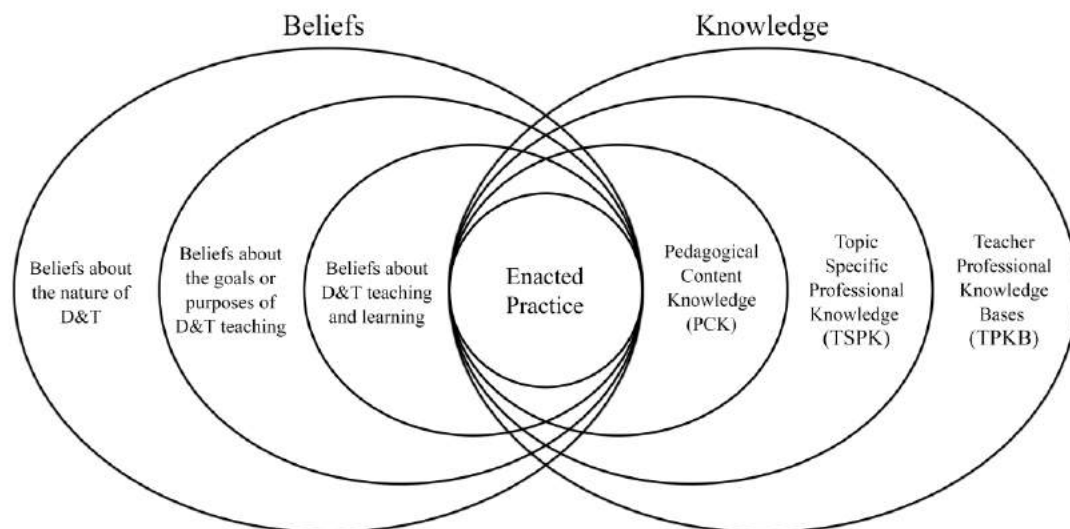


Figure 2. Theoretical model of enacted practice, teachers' beliefs and teacher knowledge in D&T.

## 6. AMPLIFIERS AND FILTERS OF PRACTICE

Situating the amplifiers and filters component of teacher professional knowledge and skill (Gess-Newsome, 2015) in the intermediary between teachers' knowledge bases and enacted practice offers an explanation to inconclusive findings between teachers' PCK, enacted practice, and student achievement (Baumert et al., 2010; Gess-Newsome et al., 2017) as the construct identifies the need to understand the various factors which may affect utopian classroom intentions. In considering factors which have the potential to mediate teachers' actions and choices in the classroom, some elements are immediately apparent. For example, Gess-Newsome (2015) highlighted the potential of; teachers' views about the societal goals for schooling, their orientation toward preferred instructional strategies, or their preferred organization of the content of their discipline, all as potential amplifiers or filters of practice. Within this however, there is an important distinction to make between factors which have the potential to affect teachers' practice holistically, such as expectations placed on the teacher in a particular school culture, and more day-to-day factors such as availability of resources. The need for such a categorisation stems from Kennedy's (2010) assertion that the educational research community may be guilty of attributional error, as researchers overestimate the power and influence of teachers' personal characteristics and practices. Instead, it is proposed that situational forces such as teachers work (time, materials, and work assignments), students, school interruptions into the classroom, and the difficulty of attending to multiple reform efforts simultaneously may have a stronger relationship to student learning than teacher quality. This problem of enactment (Kennedy, 1999) in teaching practice highlights the need to understand the different frames of reference in which teachers' practices are being discussed. Without an explicit frame of reference for observations of enacted practice, the degree to which generalisations can be made of such observations is unclear. This is perhaps more appropriate when exploring the enacted practice in D&T education as the additional variance of increased volition is facilitated by the nature of the subject. This situational frame of reference is depicted in Figure 3 by means of depicting the importance of understanding the various factors which load on a teacher's practice in a particular instance. The importance in understanding situational amplifiers and filters of practice is predicated on the concept of ecological validity. Exploring enacted practice through situating data collection instruments in the learning context, where data about the context itself may be gathered, provides greater opportunities to generalise findings in the discipline.

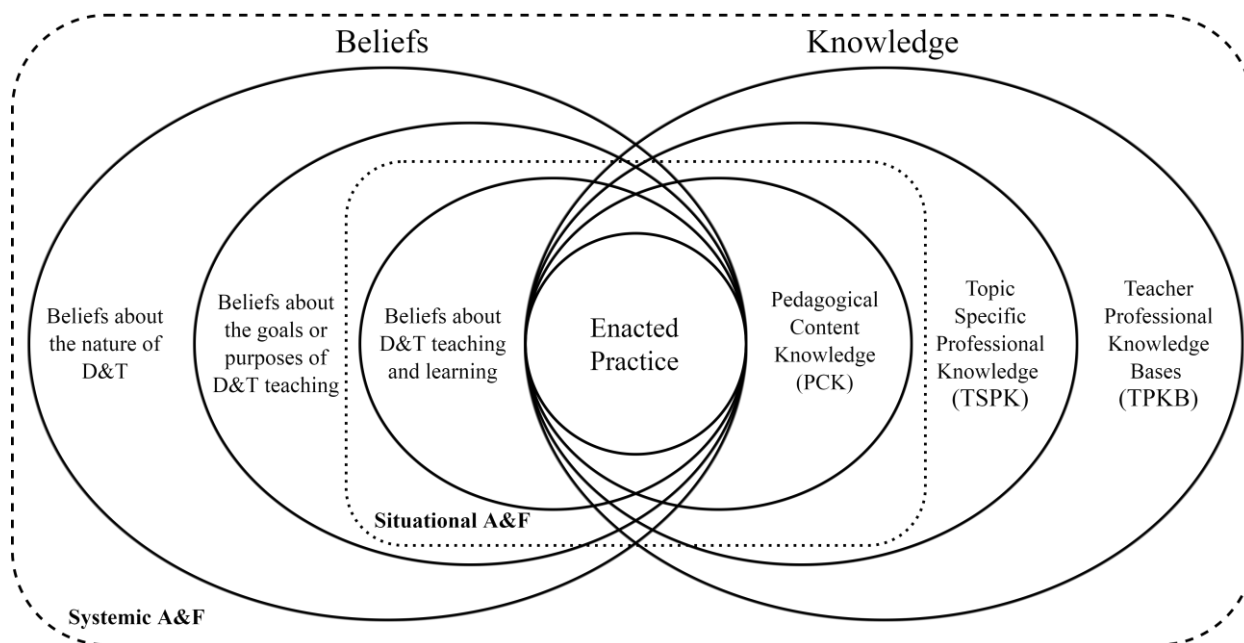


Figure 3. Ecologically situated model of enacted practice, teachers' beliefs and teacher knowledge in D&T.

Further to this, systemic amplifiers or filters can be characterised by the educational context and subsequent expectations which may be placed on teachers. Here, any factor which has the potential to affect teachers' utopian aspirations for classroom practice should be considered. Examples of such may be a misalignment between intended learning outcomes prescribed in syllabi and a highly performative assessment culture, (Porter, 2006) which may require teachers to truncate syllabi at the expense of student learning (Hyland, 2011). School or departmental ethos or 'standard practices' may also have an impact on teachers' pedagogical aspirations. These cultural factors are important due to their perceived effect on teachers' knowledge and beliefs over a sustained period of time. As with situational amplifiers and filters, the contribution of detailing (or controlling) systemic factors which load on teachers practices are essentially that of content validity. Furthermore, it is theorised that systemic amplifiers and filters may be of critical importance, due to their position as a confounding variable as work on teacher enculturation (Goodson, 1991; Tishman, Jay, & Perkins, 1993) suggests that expectations of the teaching context may influence teachers' beliefs with more time spent teaching in a particular context.

## 7. DISCUSSION AND CONCLUSION

The framework identifies the need to understand individual teachers' agendas for D&T education before factors which may act on these agendas can be identified. Triangulating teachers' beliefs about what is of importance to student learning in D&T, their beliefs about the nature of teaching and learning in the discipline, and their perspective on their enacted practices affords the unique opportunity of a self-reflective depiction of practice in the context of student performance relative to a particular context. To affect practices, a conceptual change of teachers' beliefs about the nature of teaching and learning in their discipline may be necessitated. This resonates with the earlier discussion exploring the relationship between PCK as a knowledge base and enacted practice, and offers an explanation as to why a teacher may be reluctant to utilise a particular pedagogical approach.

As the framework presented in Figure 3 is ultimately concerned with better understanding enacted practice in the discipline, it is important that the framework is read and applied in this way; from the centre out. From this perspective, observations of classroom practice have the potential to elicit teachers' PCK, specific to that educational context. It is important to note that this PCK is not necessarily representative of this teacher's PCK as a whole. Similarly, observations of or reflections on teachers' practice potentiate the elicitation of teacher ontological beliefs about the nature of the subject. Although these beliefs may not be fully representative of their beliefs about the nature of D&T, their interdependency on enacted practice is the unique contribution of this approach. The amplifiers and filters elements reinforce this contribution as they highlight the need to

understand practice from an ecological perspective. Thus, in an effort to investigate practice in the discipline from an ecological perspective, cognisant of the need to simultaneously consider the cognitive and affective factors which affect teachers' actions (Charalambous, 2015), the contribution of this research is in proposing a methodological framework to facilitate this investigation. That is not to say that research concerned with individual elements of teachers' knowledge or beliefs will not be of use. However, if generalisations are to be made about the nature of practice in the D&T, researchers must consider all of the factors that have the potential to affect enacted practices.

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# Investigating the Potential for RGT and ACJ towards deeper insights of Teacher Assessment Practices

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The evolution of advanced technology systems and the labour market for future engineers and designers are a global matter. In light of this reasoning, a global perspective on technology education becomes even more important. Assessment is key in order to bridge teaching and learning and an international perspective is needed for understanding different assessment practices in technology education. The purpose of this paper is to investigate potential methods of gaining new perspectives and understanding of teacher assessment practices. Adaptive comparative judgement (ACJ) is an assessment method that has been proven to provide valid, reliable, and feasible results for the assessment of open-ended design problems within technology/engineering education in several countries (Hartell & Skogh, 2015; Kimbell, 2012; Power & Seery, 2012; Seery, Cauty, & Phelan, 2011; Bartholomew, 2016). ACJ has also been used as an approach to compare teachers' assessment practices across countries (see e.g. Bartholomew et al, 2017). Reparatory grid theory (RGT) is a method based on George Kelly's theory of personal constructs (Kelly, 1963). RGT is used to explore informants' interpretations and views, on certain topics, for example products or other artefacts (Isaksson Persson, 2015), and teachers' assessments of portfolios in crafts/sloyd and technology education (Björklund, 2008; Lindström, 2001). The results of ACJ for assessment can be represented in a quantitative manner (Pollitt, 2012) and can be complimented with qualitative measures of think aloud protocols and or comments from informants during the judgement sessions (see e.g. Hartell & Skogh, 2015). This paper will explore the potential for, and implications of, combining RGT and ACJ outputs a richer understanding of teachers' assessment values when assessing open-ended students design portfolios and products by deploying RGT on think-aloud protocols and comments provided by judges during ACJ.

*Key words: Adaptive comparative judgement, comparative judgement, reparatory grid theory, assessment, technology education, engineering education, STEM education*

## 1. INTRODUCTION

Establishing an understanding of teachers' assessment practices with regards to design is paramount and the need to analyse teachers' values in depth is both needed and asked for (Bjurulf, 2011; Hartell, 2015; Williams, 2016). This paper reports the results from a pilot study that was undertaken with the purpose of examining the potential (if any) of using the Reparatory Grid Technique (RGT) (Kelly, 1963) as a tool for analysing the feedback comments, collected from teachers, as they assess student design work through an Adaptive Comparative Judgement software engine titled CompareAssess. This pilot study applies RGT on data collected through an on-going project investigating teachers' assessment practices and values in open-ended design across cultures in USA, UK, and Sweden (see Bartholomew, Hartell, & Strimel, 2017). We investigated the potential of RGT as a tool for deeper analyses of judge comments the feedback comments collected from



Swedish teacher judges as they compared student's design work (design products and portfolios). The results highlight the potential utility of the RGT for analysing the qualitative data collected through ACJ assessment software.

### ***1.1 Reparatory Grid Theory***

The Reparatory Grid Technique (RGT) is derived from George Kelly's work and is based on his Theory of personal constructs (Fransella, Bell & Bannister, 2004; Jankowicz, 2004; Kelly, 1963). According to this theory, people interpret and perceive the world based on their previous experiences and, as people gain new experiences, their perception of the world changes. When people interpret the world, they use multidimensional attributes, which Kelly calls constructs (Kelly, 1963). Fransella, Bell, and Bannister (2004) summarise Kelly's view on how people construe the world as "[...] we never affirm anything without simultaneously denying something" (Fransella, Bell, & Bannister, 2004, p. 7). Correspondingly, we hypothesize that a deeper understanding may be potentially obtained by examining their constructs, as obtained through an ACJ judges' comments, using the RGT.

A construct has a bipolar structure. To fully understand a person's view on a topic we need to know both dimensions of a construct. The informant can easily express one dimension, in the analysis called the emergent pole. Contrasting to this pole is the implicit pole (Fransella, Bell, & Bannister, 2004; Jankowicz, 2004). The characteristic of the implicit pole is usually defined as a contrasting quality of the emergent pole. The procedure of the RGT results in several two-dimensional constructs through the production of both implicit and emergent poles.

Every individual holds a complex and unique set of constructs. However, Kelly (1963) argues that people can belong to a cultural group that may construe experiences in the same manner as other members of that group. In this study, we hypothesize that the Swedish technology teachers, who acted as judges using ACJ in this project, all belong to a group of individuals with similar experiences concerning assessment of design and technology. For example, this group needs knowledge of the design process and should possess similar abilities, and experiences, in the analysis of the technological world. As artefacts are results of the design process, this study is inspired by RGT studies where products and other artefacts are used as sources for elicitation of constructs. A few previous examples include: consumer products (Persson, Hiort af Ornäs, & Jordan, 2007), fine metal craft (Lindström, 2001), artefacts made by pupils during lessons in technology (Björklund, 2008), consumer products (Isaksson Persson, 2015), and teaching materials (Isaksson Persson, & Gumaelius, 2016).

To elicit a construct using RGT, a common method is to present a triad of elements representing a certain topic (Fransella, Bell, & Bannister, 2004; Jankowicz, 2004). The informant then must choose two elements that have shared characteristics, which separate these items from the third element. The characteristic(s) of the two elements is the emergent pole of a construct and the characteristic(s) of the third element are the implicit pole. There are several variations of this method, for example one can use only two elements where the informant discusses how the elements are alike or different. If they are different, the two poles are specified. If they are alike the informant is asked to describe the opposite of the similarity (Fransella, Bell, & Bannister, 2004). For more detail on RGT procedure see (Isaksson Persson, 2016).

In this study, the judges' ACJ assessment procedure was compared to a RGT procedure, where two elements are compared and similar/dissimilar, traits are identified. Further, one common procedure in RGT studies is that of comparing and rating all elements to find coherence among constructs and elements. While this secondary procedure was not performed in this study we argue that through the ranking procedure of ACJ coherence between the elements may be established.

### ***1.2 Adaptive Comparative Judgement (ACJ)***

ACJ is an assessment method where judges (e.g. teachers) are presented with two pieces of student work (e.g. design portfolios), which they compare in terms of quality. The judges may base their decisions on their professional expertise, some predetermined criteria, and/or their personal beliefs. Rather than assigning any sort of score, judges are simply asked to choose one item of student work over another when presented with a pair. Following each decision, the judges are presented with another pair and the process repeats itself, producing a

rank order, or rather a continuum of student work, which signifies quality. This process repeats itself until a pre-determined time or reliability level (i.e.,  $r > .9$ ) (Pollitt, 2012). Additional statistics for further analysis are produced (e.g. Rasch model misfit statistics, judges' time in judgments). The ACJ process, and accompanying software programs (e.g., CompareAssess) which facilitate the judgments, can also allow judges to provide motives for their decisions which include the rationale on which they based their judgment (Bartholomew et al 2017; Hartell & Skogh, 2015). For a more in depth explanation of ACJ, we direct the reader to Pollitt (2012).

Within technology and engineering education, several studies have examined both the validity and reliability of the ACJ assessment method (Bartholomew, Hartell, & Strimel, 2017; Bartholomew & Yoshikawa, 2018; Hartell & Skogh, 2015; Kimbell, 2012; Seery, Canty, & Phelan, 2011). These studies have all shown high levels of consistency in teachers' judgement, even on open-ended tasks. Relatedly, Hartell and Skogh (2015) tried to unpack what teachers value as criteria for success, while assessing multimodal portfolios, having teachers provide a motive for choosing one item as better by thinking aloud during the ACJ process, which was recorded by a MP3 recorder, and then transcribed into protocols. These think aloud protocols were analysed and the study found that teachers value how students present the narrative within their portfolio. In Bartholomew et al (2017) judges from USA, UK/Ireland, and Sweden were asked to assess an open-ended design task using ACJ and provide comments in terms of feedback used for their comparative judgements. These comments have been analysed showing both consistency, and differences, between the groups of judges in various locations and cultures (see Bartholomew et al, 2018).

### ***1.3 Reparatory Grid Technique and Adaptive Comparative Judgement***

With the purpose of a deeper understanding into teachers' assessment practices and further insight into what teacher's emphasise when assessing students' work, this pilot study investigated a combinational effort of RGT and ACJ. In this investigation, the judges' ACJ assessment procedure was looked upon as similar to an RGT procedure where two elements are compared and traits are identified (both similar and different). Further, one common procedure in RGT studies is that of comparing and grading all elements to find coherence among constructs and elements. While this secondary procedure was not performed in this study, we argue that the ranking procedure of ACJ can establish similar coherence between the elements.

## **2. METHODOLOGY**

Data from an on-going research project investigating teachers' assessment practices and their values during ACJ process was used in this study to explore RGT as tool for the analysis of the judge comments collected via the ACJ process. A member of the research team collected design products and portfolios from American middle school students (12–14 year old,  $N = 760$ ), who designed pill dispensers for elderly people who enjoyed travelling (see Bartholomew, Reeve, Veon, Goodridge, Stewardson, Lee, & Nadelson, 2017). The students in this study worked in groups and produced products ( $N = 175$ ) and process portfolios ( $N = 175$ ), which were then collected for ACJ assessment by three groups of judges to assess the student work (Bartholomew et al, 2017). Judges were recruited from the USA, UK/Ireland, and Sweden and were trained in the ACJ process for this task by the researchers involved. The judge comments collected from four Swedish judges were examined for the purposes of this pilot effort. These judges all had a background in technology education in Sweden and two of them were STEM teachers in teaching years 1–6 and 4–9, one was a technology teacher for years 7–9, and one was a professor of technology education.

The analysed ACJ data included a rank order of the design work from the American middle school students and feedback comments from the Swedish judges that were collected during the ACJ process when they judged the student work. The RGT analysis includes 175 product pictures and 459 judge comments. Further analysis focused on student work ranking from 1 – 5 from the top (called W1, W2, W3, W4, and W5). The rationale for selecting these pieces of student work was to get a reasonable amount of data to achieve the overall goal for this pilot, which is to investigate the possibilities for extensive analysis of ACJ data with RGT. As a start, products with high rank order were selected as they may have potential to reflect qualities that are considered as important to the judges.








### 3. DATA ANALYSIS AND RESULTS

ACJ has similarities with construct elicitation in the RGT. A judge's comment defines a quality/characteristic that describes a difference between two elements. The difference between two elements is described in a written comment by the judge. This description of a difference may therefore be similar to the descriptions of contrasting characteristics representing the emergent and implicit pole in a construct elicited with RGT.

Table 1 provides an example of how ACJ data could potentially be arranged in alignment with RGT. To the left is product Work 1 (W1), which received a ranking as the best product overall according to the Swedish judges. All comments this product received from the Swedish judges are presented (Table 1, comments 1-5). Under the heading ELEMENTS (products) are the products that in comparison with W1 elicited the comments from the judges.

In this analysis, comments 4 and 5 are considered to be the carriers of more information than comments 1-3. Comments 4 and 5 are results from assessment sessions where W1 is compared with W2, (rank order two). Comments 1-3 are results from comparisons with W1 and other products not included in top five rankings (rank order 65, 74, 141). In this study all comments are regarded, but a comparison between elements with similarly high rank orders provides an interesting glimpse into the specific qualities appreciated by the judges. In RGT the whole construct, both the emergent and the implicit poles, informs us about the judges' view on the topic. Construct D and E (Table 1) showcases the comments and product picture of W1 and W2. Based on the comments provided we hypothesize that an important quality to judges was functionality, as demonstrated in the judge comments.

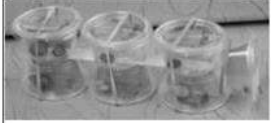



Table 1: example of ACJ data arranged in accordance with RGT

		Swedish Judges				
		ELEMENTS (products)				
		W2	Other			Implicit pole
			W65	W74	W141	
<b>Emergent pole</b>						
 W1	<b>Construct A.</b> A is best in its design and information. (Comment 1, Judge01 comparing W1 and Other)				X	
 W1	<b>Construct B.</b> Easy to see if the pills are taken. (Comment 2, Judge03 comparing W1 and Other)		X			
 W1	<b>Construct C.</b> It (A) looks to be more functional and it is also simple and stylish. (Comment 3, Judge05 comparing W1 and Other)		X			
 W1	<b>Construct D.</b> B provides a better overview. (Comment 4, Judge01 comparing W1 and W2)	X				 W2
 W1	<b>Construct E.</b> I liked that it was simple to see if I had missed to take the pills. And I like the construction. (Comment 5, Judge03 comparing W1 and W2)	X				 W2

W<sub>n</sub> = rank order  
Other = Other than top five elements

It is also interesting to regard the other comments related to W2 (Table 2). In the assessment sessions represented W2 was the winner. In construct F (Table 2) W2 was compared with W4 (rank order four). The winning quality derived from the analysis showed that W2 was better organised than W4 (Table 2, comment 6). Considering comment 4 (Table 1, construct D) we derived that W1 won because it provided a better overview than W2. While overview and organised were important aspects of a winning quality to Judge01, we posit a better understanding of the quality Overview-Organised would be understood if the opposed characteristics were known (Kelly, 1963). In other words, both the emergent pole and the implicit would be useful for further analysis.

Table 2: shows the constructs where W2 is the winner

Swedish Judges					
ELEMENTS (products)					
		W4	Other		Implicit pole 
			W26	W53	
<b>Emergent pole</b>					
<i>Construct F.</i> B is better organised.  (Comment 6, Judge01 comparing W2 and W1) W2		X			
<i>Construct G.</i> Good construction/design.  (Comment 7, Judge03 comparing W2 and Other) W2				X	
<i>Construct H.</i> B is simple but well-functioning. Well worked/thorough model.  (Comment 8, Judge05 comparing W2 and Other) W2			X		

*W<sub>n</sub>* = rank order

Other = Other than top five elements

#### 4. DISCUSSION

This initial effort was conducted with the purpose of investigating the potential for RGT as a possible tool for qualitatively analysing feedback comments elicited from ACJ process. Our results revealed promise for using RGT in the further analysis of ACJ comment data. We suggest that, based on our analysis, functionality was important to the Swedish judges as was the quality of Overview-Organised.

Full constructs (Table 1, constructs D and E; Table 2, constructs F) with product pictures representing both poles were elicited while full constructs in words were not elicited in this analysis model (Table 2). According to Kelly (1963) data from a constructs' both poles are aspects of the same underlying phenomenon. Therefore, data from both poles would likely provide a more robust opportunity for in-depth analysis and understanding.

The experiences from this first pilot study opened further investigation possibilities related to the present data, as well as possibilities to improve the combination of ACJ and RGT. For example the results point to: Additional possibilities for analysis related to the scope of this pilot study.

Image analysis may increase an understanding of the constructs.

Repeated analysis with the comments from the US and UK judges may reveal additional insights.

Possibilities exist related to using RGT for expanded data analysis in the scope of the on-going international comparative study on cultural design values (Bartholomew et al, 2017).

The results point to possibilities for further development of the combination of ACJ and RGT.

In this study the judges were asked to provide a motive for why they chose one on top of the other. From this study we have learned that it would be even better if they were given instructions that guide the judges to comment on both objects, this with the purpose to reveal full constructs. Judges need to describe why they chose an object and why they do not chose the other one. To gain richer insights on their motives, another possible option to develop the methodology even further could be to use think aloud protocols where judges think-out loud instead of typing their comments (see Hartell and Skogh, 2015). However, having judges think out loud provides more data but not necessarily richer data.

Complement ACJ with face-to-face interview using RGT.

Conduct similar analysis on qualitative data gained from ACJ trials, in technology education and also other subjects with the purpose of understanding teachers' assessment practices and feed that into learning activities for students.

## 5. CONCLUSION

Results from this pilot study highlight possible benefits of combining RGT and ACJ as a method for unpacking judges' assessment practices, and eliciting evidence of their values and beliefs. As this is a pilot study, one should be cautious to conclude, however the importance of asking judges why they choose and also ask why they do not chose object during ACJ session must be considered in future work with this combined method. From judges' comments results indicate that judges in this research valued functionality in students' work.

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# Addressing the issue of bias in the measurement of reliability in the method of Adaptive Comparative Judgment

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The method of Adaptive Comparative Judgment (ACJ) is a modification of the Comparative Judgment method (CJ) originally proposed by L. Thurstone, which proposed using pairwise comparisons to obtain measurements of a particular trait from the objects being compared. The difference between CJ and ACJ is that the latter uses adaptivity (as in Computerised Adaptive Testing), in the process of choosing the pairs of objects to be presented in the comparisons. In an adaptive process, objects with similar quality are “intelligently” presented in the pairwise comparisons, improving the efficiency of the method by increasing the amount of statistical information contained in each judgment and therefore enhancing the level of reliability from the measurement. However, in the last couple of years there have been studies claiming that the measured reliability figures produced by the ACJ method could be artificially inflated, and that this effect is intrinsic to the adaptive process. In view of that, this paper aims to provide an independent investigation on the issue and propose a solution that would allow the exploitation of the benefits of adaptivity whilst controlling any possible artificial inflation of the reliability.

*Key Words: Adaptive Comparative Judgment, Marking, Reliability, Assessment Methods.*

## 1. INTRODUCTION

The method of Adaptive Comparative Judgment (ACJ, Pollitt 2012) is a modification of the Comparative Judgment method (CJ) introduced by L. Thurstone (1927) which proposed using pairwise comparisons to obtain measurements of a particular trait from these objects. The main application of the CJ/ACJ methods has been in education, by using the professional judgment of teachers to measure the quality of pieces of student work (“objects”) as an alternative form of marking (Kimbell, et al. 2007; Bramley 2007; Jones, et al. 2016).

The difference between CJ and ACJ is that the latter uses adaptivity as in Computerised Adaptive Testing (Straetmans & Eggen, 1998), in the process of choosing the pairs of objects to be presented in the comparisons. One of the strongest arguments for ACJ is that the use of adaptivity should improve the efficiency of the method by increasing the amount of statistical information contained in each judgement and therefore enhancing the level of reliability from the measurement (Pollitt, 2012). However, in the last couple of years there have been studies claiming that the reliability figures produced by the ACJ method could be artificially inflated, and that this effect is intrinsic to the adaptive process of pair allocation (Bramley 2015, 2018). In view of that, this paper aims to provide an independent investigation on the issue.

This study is based on simulations which rely on the algorithm of the CompareAssess software from the company Digital Assess, which is one of the main software products using adaptivity in CJ sessions at the time of writing.

## 2. METHOD: SIMULATION OF AN ACJ SESSION

In order to test the effect of adaptivity in a comparative judgment session, an ACJ session is simulated numerous times from different hypotheses. These are based on the distribution of the “true quality” from the objects being judged in the session, and the level of adaptivity used to determine the allocated pairs of objects.

In all simulations, the “true quality” parameters of 100 objects are generated based on an initial hypothesis of their distribution. Then, these objects are paired based on different levels of adaptivity. All objects are judged the same number of times, and the session is simulated to last during 40 rounds of judgments (in this case a new round occurs every 50 judgments). Each hypothesis is simulated independently 40 times.

Independent judgments are simulated from following the Rasch formulation of Thurstone’s case V, where the probability of an object A to be judged as having a better quality (win) than an object B is a function of the difference of the quality parameters ( $p_A, p_B$ ) between the objects being judged, as described in Formula 1 (Andrich, 1978).

$$prob(A \text{ win over } B) = \frac{e^{(p_A - p_B)}}{1 + e^{(p_A - p_B)}} \quad (1)$$

$p_A, p_B$  are represented in the logit scale which is interpreted as the log of the odds of the outcome of the comparison of an object with parameter  $p$  winning a comparison over an object of average quality parameter of 0.

In the simulation, a win or loss in the judgments is obtained by comparing the modelled probability of a win from Formula 1 with a random number from an uniform distribution in the range 0-1. In a judgment between an object A and B, object A wins if the modelled probability is greater than the random number and “B” would win in the opposite case.

The measured quality parameters and standard errors are estimated from the simulated pair comparison data by fitting the Rasch formulation to the data with a maximum likelihood (ML) procedure as shown in Pollitt, 2012. An object parameter estimation is performed and reported after each round, starting after round 4 (200 comparisons).

### ***2.1. Hypothesis on the width of the distribution of quality parameters***

For simplicity, the object parameter values are assumed to be normally distributed with a fixed mean value on 0, and a variable width or standard deviation (SD). In this study, the width is interpreted as the average power of discrimination that the judges have over the quality of the scripts.

The SD of the distribution of the "true" quality parameters is chosen from 5 options (0, 0.9, 1.9, 3.6 and 6.6 logits). The specific SD reflects the nature of the possible judgements that can be made - these broadly fall into 3 categories:

- (1) No discrimination between the quality of objects, the judge is providing random choices (extreme ‘coin flip’ experiment).
  - SD: 0.0 logits.
- (2) Medium discrimination. Judges might not always find consensus with each other’s judgments (student peer-review sessions, non-experienced judges, misfitting judge, objects with very similar qualities, etc).
  - SD: 0.9 logits,
  - SD: 1.9 logits,
  - SD: 3.6 logits.
- (3) High discrimination and consensus (expert judges or a sample of objects with a very wide variety of qualities).
  - SD: 6.6 logits.



The non-extreme SD values chosen to generate the initial parameters have been observed in real ACJ sessions conducted with the CompareAssess software, therefore are considered as valid hypotheses. The range of these hypotheses should cover the different types of scenarios that can be observed in a session, in terms of the level of discrimination and expertise of the judges.

## 2.2. Levels of Adaptivity

In this study, the process of allocating the pairs to be judged is the following:

Swiss rounds: In the first 4 rounds, the objects are matched by the so-called Swiss Tournament method described by Pollitt, 2012.

- First round: 50 pairs of objects are randomly chosen.
- Second round: objects are paired based on their result in the previous round, objects that won their previous judgment are matched to other objects of the same type. The same happens with objects that lost their judgment in the first round.
- In the third and fourth round the objects are matched with objects that have similar scores, in terms of number of wins or losses collected in previous rounds.

Adjustment rounds: After 4 rounds have been completed, the adaptive rounds begin. These consist in using the quality parameter value of the objects (estimated after the previous round) to choose the object that it will be judged against. This is done in the following way:

For an object A, the object B chosen to be judged against in a pairwise comparison is the one that minimises the value of  $|\Delta|$ , where this is estimated as shown in Formula 2.

$$\Delta = |p_A - p_B| - \text{Gap} \quad (2)$$

where “Gap” in this study is defined as the level of adaptivity and represents the minimum separation that the estimated parameters of objects A and B have. Theoretically, the smaller the “Gap” variable, the larger is the statistical information their judgment brings to the system.

In this study, for each width hypothesis, different levels of adaptivity are tested. Furthermore, an algorithm that randomly allocates pairs to be judged (no adaptivity) is also tested for comparison with the adaptive algorithms. The following levels of adaptivity are simulated:

- 4 Swiss rounds + 36 rounds with:
  - “Gap” of 0.0 logit (odds of A winning over B in a judgment is 50/50)
  - “Gap” of 0.7 logit (odds of 67/33)
  - “Gap” of 1.5 logit (odds of 82/18)
  - “Gap” of 2.5 logit (odds of 92/8)
  - “Gap” of 4.0 logit (odds of 98/2)
- Random allocations in all 40 rounds

In each simulation, all objects get compared the same number of times and is linked directly or indirectly with every other object in the session.

## 2.3 Performance Metrics

In order to measure the performance of the ACJ process for the different hypotheses, a number of metrics are computed. The following definitions are based on Classical Test theory principles (Brennan 2011), Rasch modelling (Andrich 1982), and the nomenclature used in Bramley’s 2015 paper:

The “True” standard deviation of the estimated parameter values and the Scale Separation Reliability (“SSR”) of the result are central metrics to this study, defined in the following way:

$$(TrueSD)^2 = (ObservedSD)^2 - MSE \quad (3)$$

$$SSR = (TrueSD)^2 / (ObservedSD)^2 \quad (4)$$

where MSE is the mean squared standard error across the objects. The standard errors are estimated as the inverse of the square root of the object information as shown in Pollitt, 2012.

The “True Reliability” is defined as the square of the Pearson correlation between the generated object parameters in the simulation and the object parameters estimated from the judgment data.

$$TrueReliability = (\rho_{observed, trueparameters})^2 \quad (5)$$

One of the main goals of this study is to measure the effect on the different levels of adaptivity in creating a bias on the reported “SSR” compared it to the “True Reliability” value for each experiment. For this, a “Bias” metric is defined as shown in Formula 6.

$$Bias = (TrueReliability - SSR) \quad (6)$$

The ratio between the true standard deviation and the generated one is defined in the following:

$$RatioSD = (TrueSD) / (GeneratedSD) \quad (7)$$

Using these metrics it is possible to optimise the level of adaptivity that maximises the “True Reliability” achieved and reduces the “Bias” metric. Furthermore, by measuring these parameters round by round, it is possible to determine how many rounds are needed to generate an accurate measurement.

### 3. RESULTS

For each simulation the “Bias”, “Ratio SD”, “SSR” and “True Reliability” metrics are measured from rounds 5 to 40. The value of these metrics (estimated in 40 independent simulations) as function of the number of rounds is represented in profile figures. In all the following figures the marker shows the central tendency of the metric in that round and the errors correspond to the 95% confidence interval of that measurement.

#### 3.1 Performance of the ACJ process for different levels of adaptivity

The performance of an ACJ session is measured through the “True Reliability” metric (Formula 5). This metric as a function of the number of rounds for different width hypothesis and levels of adaptivity is shown in Figure 1.

The figures show an relationship between the optimal allocation method for the best performance of the system and the width of the initial object parameter value. For narrow widths, where there is poor consistency/consensus among the judges, the optimal allocation appears to be towards the random allocation. On the other hand, for wider standard deviations of the initial object parameter (more consensus and discrimination power of the judges), the adaptivity appears to bring important gains in the performance.

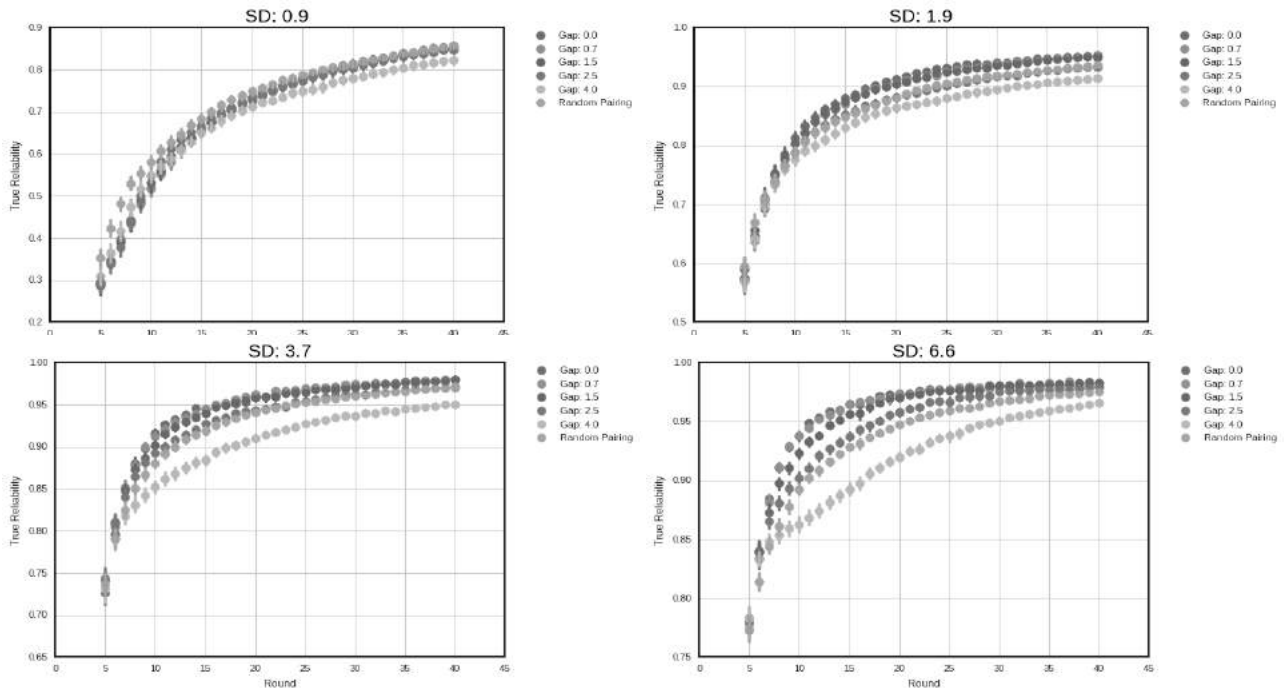


Figure 1. “True Reliability” metric as a function of the number of rounds in ACJ session simulations for different levels of adaptivity. Each figure shows the “True Reliability” performance for the different hypothesised widths (SD) of the distribution of the quality parameters.

### 3.2 Measurement of the “SSR” metric

The “True Reliability” as shown in Figure 1, cannot be intrinsically measured in a real ACJ session. An estimation of this reliability is performed using the “SSR” metric (Formula 4). This metric, as a function of the number of rounds for different width hypothesis and levels of adaptivity, is shown in Figure 2.

The behaviour of the “SSR” metric in the extreme “coin flip” case (SD of 0.0 logits) is equivalent to the one reported in Bramley’s 2015 paper. In a highly adaptive case, the reliability which should be 0, is measured to be between 0.6-0.8. Nonetheless, by reducing slightly the level of activity used (“Gap” > 0 logits), the “SSR” metric tends to get corrected as the more rounds of judgments are simulated. The larger the “Gap” variable, the faster this correction occurs (in terms of number of rounds). This effect is also observed in other narrow width hypothesis (SD of 0.9 logits), where an inflation on the “SSR” parameter is observed in early rounds, which gets corrected as more data is added to the system.

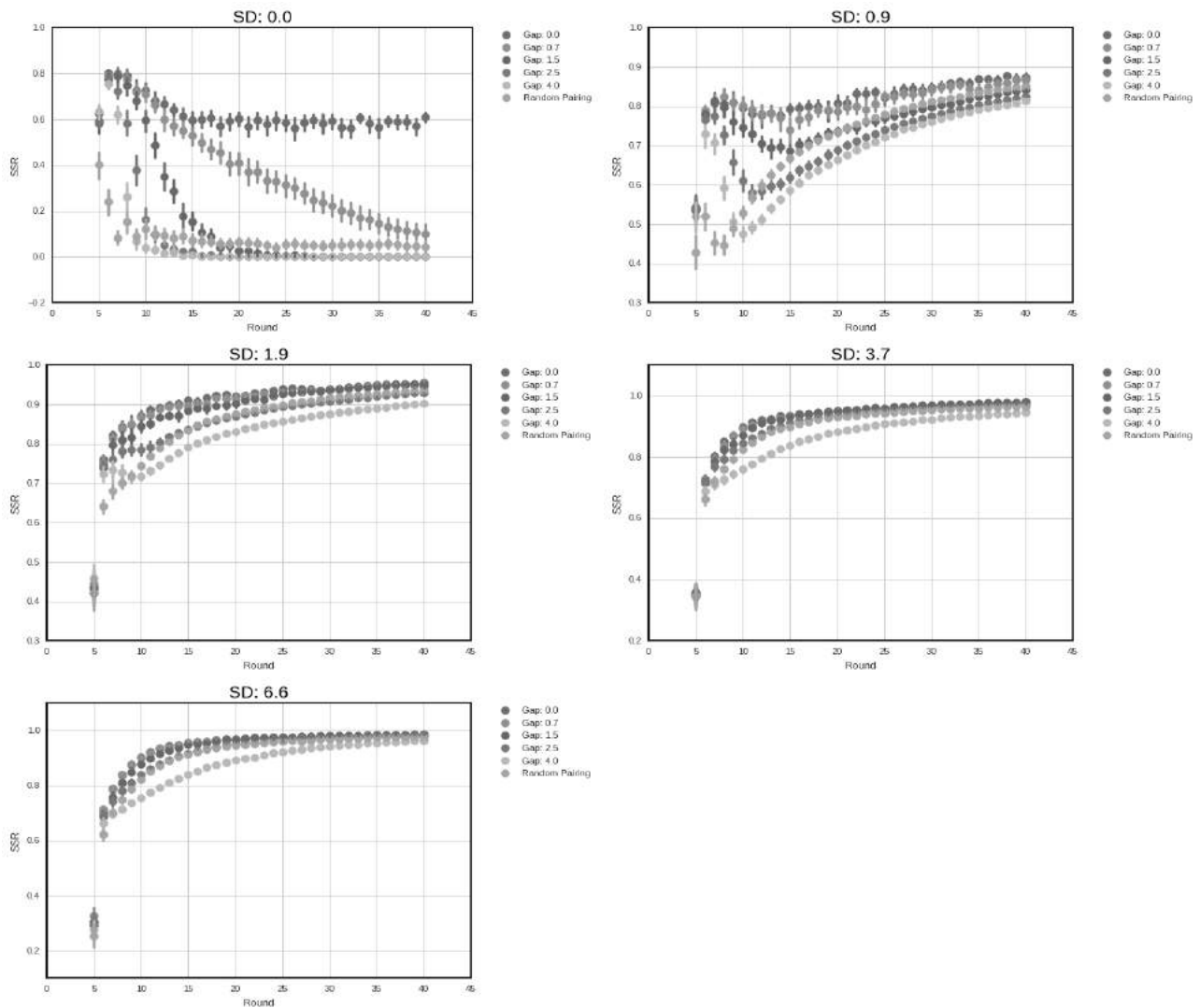


Figure 2. Scale Separation Reliability (“SSR”) as a function of the number of rounds in ACJ session simulations for different levels of adaptivity. Each figure the shows the “SSR” metric for the different hypothesised widths (SD) of the distribution of the quality parameters.

### 3.3 Bias on the measurement of the SSR metric

The previous sections have discussed the “True Reliability” and “SSR” metric as a function of the number of rounds simulated in a session. There is a clear mismatch in the way that these two metrics evolve with the number of rounds, which means that the “SSR” metric is not reflecting the real value of the reliability and introducing a bias to the system. To specifically measure this effect, the “Bias” metric (Formula 6) as a function of the number of rounds for different width hypothesis and levels of adaptivity are shown in Figure 3.

In all widths and levels of adaptivity a sizeable bias is observed particularly in the first rounds. The size of the “Bias” metric tends to decrease as more rounds are simulated. The size of the “Bias” metric and its sign is dependent on the initial object parameter width, this means that the narrower the width hypothesis, the more prone the system is to overestimate the reliability.

The higher the level of adaptivity, the more rounds are needed to reach a result with a controlled “Bias” metric (less than 5%). As it was also seen in Figure 2, the extreme ‘coin flip’ experiment (SD of 0.0 logits) shows a very large bias particularly with high level of adaptivity. A medium level of adaptivity such as “Gap” of 2.5 logits shows an outcome that reaches controlled levels of bias after 10 to 12 rounds for all non-extreme width hypothesis.

In random allocations (no adaptivity) the size of the bias observed is significantly smaller than the system with high levels of adaptivity. However, a bias is still observed in the first rounds where the computed “SSR” seems to underestimate the “True Reliability” (in non-extreme cases).

Table 1 shows the mean values of the performance metrics shown in Figures 1 and 3 when 12 rounds of judgment have been completed (typical users of the ACJ method expect to have a reliable result at this point).

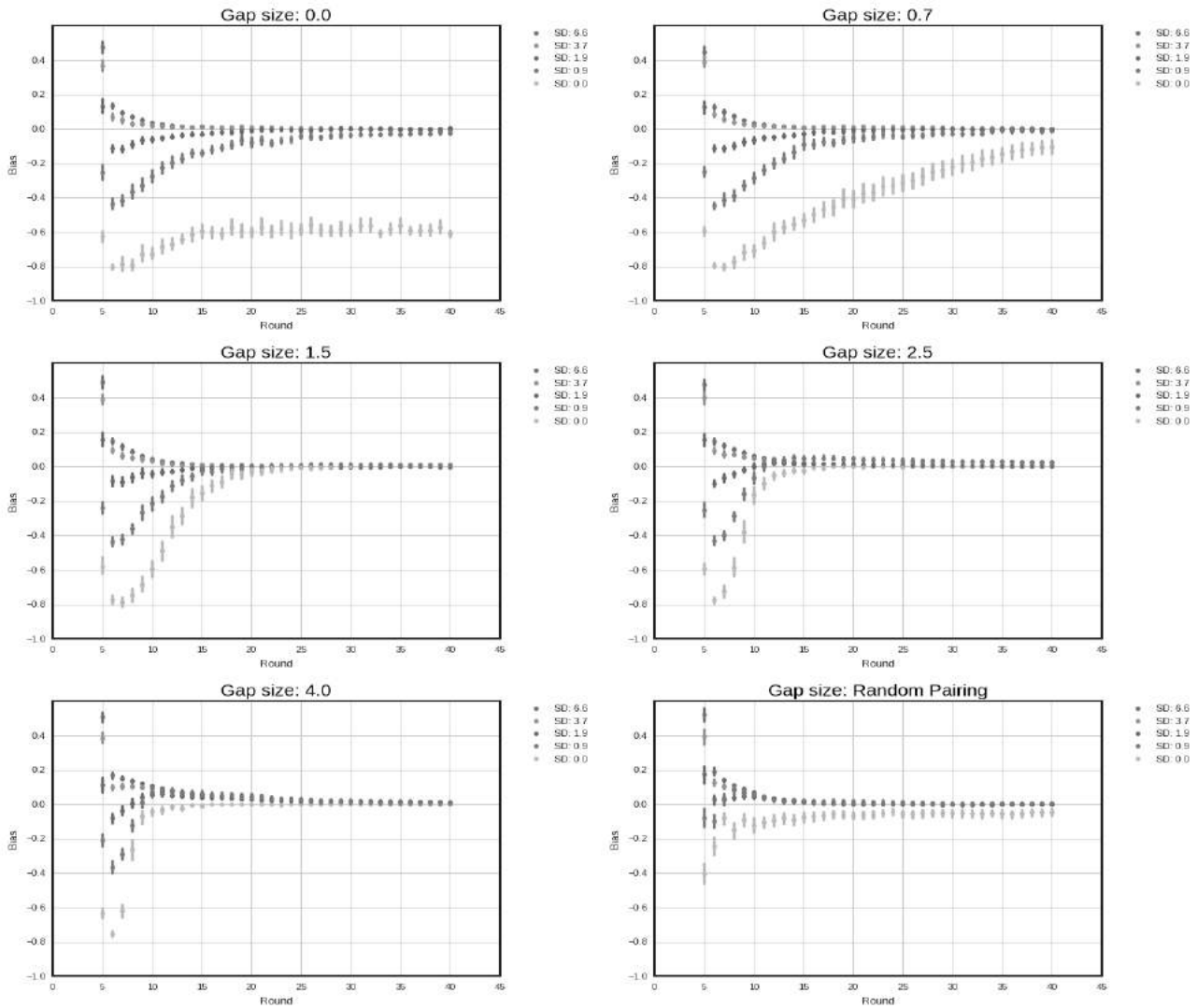


Figure 3. “Bias” metric as a function of the number of rounds in ACJ session simulations for different width (SD) hypotheses. Each figure shows the behaviour of the “Bias” for a different level of adaptivity.

Table 1. Mean values of the “Bias”, “True Reliability” and “Ratio SD” metrics obtained from simulations after 12 rounds of judgment have been completed. These metrics are shown for for the different width hypotheses and adaptivity level (“Gap” as shown in Formula 2).

Generated SD	Gap (logits)	Bias	True Reliability	Ratio SD
0.9	0.0	-0.196	0.582	1.564
0.9	0.7	-0.199	0.580	1.558
0.9	1.5	-0.109	0.594	1.227
0.9	2.5	0.028	0.611	0.912
0.9	4.0	0.075	0.587	0.791
0.9	Random	0.029	0.627	0.911
1.9	0.0	-0.044	0.847	1.216
1.9	0.7	-0.047	0.839	1.183
1.9	1.5	-0.027	0.840	1.095
1.9	2.5	0.018	0.823	0.890
1.9	4.0	0.053	0.799	0.790
1.9	Random	0.033	0.82	0.875
3.6	0.0	0.012	0.932	0.802
3.6	0.7	0.017	0.929	0.762
3.6	1.5	0.013	0.923	0.801
3.6	2.5	0.031	0.908	0.743
3.6	4.0	0.07	0.868	0.603
3.6	Random	0.034	0.898	0.725
6.6	0.0	0.020	0.953	0.515
6.6	0.7	0.013	0.951	0.550
6.6	1.5	0.021	0.938	0.501
6.6	2.5	0.041	0.920	0.461
6.6	4.0	0.080	0.874	0.371
6.6	Random	0.037	0.908	0.446

## 4. DISCUSSION

Results from ACJ simulations shown in the previous section can be summarised in the following points:

- An adaptive algorithm maximises the performance of the system in terms of the “True Reliability” in cases where there is high discrimination, which can be likened to having expert judges demonstrating a high level of consensus. On the other hand, the adaptivity process also brings a bias in the measurement of the reliability in cases where the consensus/consistency in the judges is poor. The size of the bias in the reliability is linked to the level of adaptivity used in the simulation and the amount of rounds the simulation has completed.
- The minimum number of rounds a system needs before there is enough information available to make sense of the reported reliability figures depends on the level of adaptivity in the system. A highly adaptive system (“Gap” of 0.0 logits), might need a minimum of 25 rounds, to reach an accuracy within 5% for all non-extreme width hypotheses. The medium adaptivity level might need between 12 to 15 rounds (“Gap” of 2.5 and 1.5 logits respectively).

The source of bias in an adaptive system can be traced to the fact that initially (in early rounds), there is too much uncertainty in the objects parameter measurements to accurately use the information function in the pair allocation process. Furthermore, in a highly adaptive system (“Gap” of 0.0 logits) which seems to be the one studied in the Bramley papers (2015, 2018), the algorithm is never likely to ever pair objects that appear to be very different which creates an artificial enhancement of the width of parameters in systems with a large noise component (narrow SD) in which the most extreme effect is the one observed in the ‘coin flip’ experiment. Nevertheless, this does not mean that adaptivity can never be used in any case of comparative judgments. This study has found that adaptivity does not bring an important bias in cases where judges show high discrimination and it improves significantly the performance of the system in terms of the “True Reliability” reached. Furthermore, for all different levels discrimination/consensus, the results obtained in this paper show that adaptivity can be used if enough data is provided to the system.

### 4.1 Recommendations

Based on the studies shown in this paper, a number recommendations to ACJ practitioners are drawn:

- This study advises against using the highest level of adaptivity (Gap of 0.0 logits), where the pair of objects allocated are the closest in its parameter values. Not only due to the observed effect on the accuracy of the “SSR” metric, but also because this configuration would make the task of the judges to be quite difficult, by constantly having to choose among very similar objects in quality.
- It is recommended to run an ACJ session with a “controlled” level of adaptivity, translated by using a minimum “Gap” size to separate the allocated objects. From this study, it can be concluded that values from 1.5 to 2.5 logits of separation can provide enough control on the measured bias.
- Depending on the chosen “Gap” value used in the session, there is a minimum number of rounds that have to occur before trusting the “SSR” metric as a reliability measurement. For a “Gap” vale of 1.5 logits there should be a minimum of 15 rounds, while for a separation of 2.5 logits it can be 12 rounds.
- 

ACJ sessions that follow these recommendations in the pair-allocation process and minimum number of rounds should result on accurate measurements of reliability. These sessions can then be used for summative assessments in cases where sufficient reliability values have been found.

## 5. CONCLUSIONS

In this paper the issue of bias on the measurement of reliability in ACJ sessions has been studied. This investigation consisted of simulated ACJ sessions under different configurations of adaptivity and judge discrimination.

This study has found that indeed there is bias observed, particularly where the consensus/consistency between the judges is poor. Furthermore, this investigation shows that adaptivity does bring a gain in the potential of sessions in comparison to non-adaptive CJ methods, principally in cases where there is high discrimination from the judges, i.e. where the judges can be considered as experts within the context being assessed. In view of this, a number recommendations are made with regards to the use of adaptivity and thus to reduce the size of the bias. These recommendations consist of using a ‘controlled’ level of adaptivity (use of a minimum separation “Gap” in the pair allocation) and completing a minimum number of rounds before use the “SSR” metric as an accurate measurement of reliability.

These recommendations have been tested in small scale real sessions with satisfactory results. However, a more complete study using larger scoped real sessions and judges (as in Bramley, Vitello, 2018) would establish an interesting basis for more in-depth investigations and analysis.

Digital Assess, the company that produces the CompareAssess software used to facilitate this study has already implemented the recommendations of this paper and continues to do research to improve the performance of the method.

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# Pre-service Teachers' Subject Knowledge in Secondary Design and Technology: Findings from an Empirical Study

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The paper draws on a doctoral study about the development of subject knowledge by pre-service teachers of Design and Technology (D&T) in secondary schools in England. The study aimed to throw light on their lived experience of developing subject knowledge whilst on placement in schools. It was anticipated that this would help to identify factors that shape what is learned and the ways in which pre-service teachers may be better prepared for placement. The study made use of phenomenology as a methodological approach in order to capture the lived experience of developing knowledge through the eyes of pre-service teachers. Empirical data was gathered through a process of interviewing 11 participants three times during the course of one academic year. Processes of data reduction and explication were undertaken to explore individual experiences and aspects that they had in common.

*Key Words: Subject knowledge, Phenomenology, Pre-service teachers.*

## 1. INTRODUCTION

Developing appropriate subject knowledge is recognised by many authors including McNamara (1991) and Ellis (2010) as an essential part of becoming a teacher. Given the short period of time that most pre-service teachers have to develop their understanding of subject knowledge, how exactly they develop their knowledge is of critical importance. Teacher educators running courses of initial teacher education in England are expected to audit beginning teachers' subject knowledge and track this throughout their training. An assessment of such tracking has formed part of the inspection regime (Ofsted, 2008) for some time, making it a priority for teacher educators in an age of considerable accountability. Such was the continuing interest in subject knowledge as a part of teacher education in 2007 that the Training and Development Agency for Schools produced a booklet entitled *Developing trainees' subject knowledge for teaching* (TDA, 2007) and held national subject seminars to discuss it. To the current day they remains considerable interest in subject knowledge and this study aimed to provide insights into the lived experience of pre-service teachers whilst on placement.

## 2. LITERATURE REVIEW

There has been an expectation that those running courses of initial teacher education will audit pre-service teachers' subject knowledge and track this throughout their training. An assessment of such tracking has formed part of the inspection regime (Ofsted, 2008) for some time, making it a priority for teacher educators in an age of increasing accountability. In addition, the government's white paper on education (DfE, 2016a) suggests that subject knowledge is an essential component. Ellis (2007b) has made the case for an increased focus on what pre-service teachers know about their specialist area and suggested that it is important to 'problematise' subject knowledge and not take it for granted. For him, focusing teacher education's work on stimulating, supporting and, indeed, researching subject knowledge development in school settings enables us to take subject knowledge much more seriously than getting beginning teachers to tick lists and identify 'gaps'.

The relationship between pedagogical knowledge and subject knowledge has been discussed by a number of authors. Mantyla and Nousiainen (2014) suggest that subject knowledge is often considered a pre-requisite to developing pedagogical approaches. For McKewan and Bull (1991), however, all content knowledge has a pedagogical dimension and the two elements cannot be separated. Other authors such as Burn, Childs, and McNicholl (2007) along with Herold and Waring (2011) explore the experience of pre-service teachers and

their interpretation of subject knowledge. There are also those that have sought to find ways of assessing and improving subject knowledge such as Lannin et al. (2013) and Mantyla and Nousiainen (2014). In this literature there was discussion of teaching as a profession and the knowledge that teachers require being defined as professional knowledge. Some authors have attempted to show the relationships between areas of knowledge that pre-service teachers need to acquire for successful teaching. Within teacher education one of the most significant of these models was a model of professional knowledge proposed by Banks, Leach, and Moon (1999).

Those researching the nature of subject knowledge in schools will not get far without meeting the concept of pedagogical content knowledge (PCK). The term has been attributed to L. Shulman (1986) who discussed different types of knowledge used by teachers and their relationship with each other. One of the criticisms of the work of L. Shulman (1986) has been that of the objective nature of PCK in which the active role of the individual is not really considered. Looking at subject knowledge from a constructivist point of view, Cochran, DeRuiter, and King (1993) consider the term knowledge unhelpful and make the case for the adoption of pedagogical content knowing as a more dynamic concept that views the individual teacher as active.

Within Design and Technology, Banks and Barlex (1999) used the model of personal subject construct developed by Banks et al. (1999) to develop what they called the DEPTH tool. This model located subject knowledge as a key element of the professional knowledge needed by pre-service teachers. On revisiting the model developed, and taking on board critique from Ellis (2007a) about the static view of knowledge it suggested, Banks (2008) proposed that it should be seen as existing in dynamic equilibrium. He suggests that a knowledge construction metaphor is appropriate in explaining the interaction between the different elements involved. More recently, MacGregor (2013) explored the life histories of pre-service teachers through the use of narrative analysis in order to throw light on factors affecting the formation of professional identity. She highlighted the importance of personal beliefs in mediating professional identity and draws attention to ways in which their existing subject knowledge helped to support them when establishing themselves as teachers.

It was decided not to use any pre-existing model or conceptual framework, such as the Minimum Competences document (DATA 1995, 2003, 2013) which has dominated the narrative in England, or the DEPTH tool (Banks and Barlex 1999). Rather, use was made of a more grounded approach to capture the essence of pre-service teachers' experience as they developed their subject knowledge.

### **3. METHODOLOGY**

In exploring the lived experience of individuals, a phenomenological research design was adopted making use of semi-structured interviews where additional and supplementary questions could be asked in order to get as much information about their experiences as possible (Brinkman & Kvale 2015). Eleven participants studying a one-year PGCE course were involved in one-to-one interviews undertaken in December, March and June during the course of one academic year and all started with the same question which proved helpful in framing the conversation. Processes of identifying significant statements, horizontalisation and reduction were used extensively to explicate the data. In addition, coding and categorising using NVIVO was also explored. Individual narratives were drawn up and are reported elsewhere. For this paper the connections between them are discussed. These 'wholist interpretations' (Van Manen 1990) were identified through a process of interpretation and dwelling on the data and identifying meaningful aspects of the experience of participants. All aspects have been subjected to imaginative variation and consequently are all essential to describe the phenomena.

### **4. FINDINGS**

#### ***4.1. Relationships***

One of the most significant findings was the impact that relationships with teachers had on participants and the ways in which it affected the development of subject knowledge. This aspect was not only significant in terms of the number of times it appeared across the data, but also in terms of the weight that it carried for their experience overall. Where a positive relationship was developed with teachers it clearly supported the

participants' acquisition of subject knowledge and this had an impact on their development as a whole. For others, however, the relationship was more strained. Simply asking questions of the mentor, or seeking advice, was seen as problematic. Here, assumptions of existing knowledge, and the experience of the pre-service teacher, had an effect on the interaction and, as a result, made it harder for the individual to gain the support needed to develop their subject knowledge. Other examples of where the relationships with teachers were less favourable, included high levels of intervention in the activities being undertaken by participants.

#### **4.2. *Emotion***

Becoming a teacher within secondary schools can be demanding for anyone with a good deal of pre-existing subject knowledge and can place emotional demands in individuals. For those pre-service teachers who are acquiring new subject knowledge in order to teach pupils in unfamiliar environments, with unfamiliar equipment and resources, the demands can be quite significant. It was clear from the data gathered that for some of the participants their experiences on placement had been emotional at times. The emotional responses had clearly affected their subject knowledge development as well as playing a part in shaping their school experience as a whole.

#### **4.3. *Comparisons***

Pre-service teachers choosing to undertake a postgraduate course of study in teacher education generally begin with at least some relevant subject knowledge and it is not surprising that some comparisons were made between their own personal experience of the subject and what they found whilst on placement. A number of participants talked about drawing on their own skills from the time when they were at school and university and how previously buried knowledge re-emerged. For one participant in particular this was something that continued through the course and was the subject of conversation during all of the interviews.

Several talked about trying to essentially re-create the experience they had when in school, in terms of content and pedagogy. Their feeling was that the way in which they had develop their skills and knowledge was very good and the right way of doing things. For many pre-service teachers, their desire to become a teacher is often as a result of experiences at school and their admiration for an inspiring teacher. The desire to reproduce the positive experiences they had is therefore not too surprising.

#### **4.4. *Adaptation***

Adjusting to the role of the teacher was one of the forms of adaptation that most of the participants experienced on entering their placement settings. Interestingly, adaptation was a feature of the conversations that took place at the beginning of the course but was not mentioned at all in relation to moving to their second placement. Sometimes this was a case of finding ways of fitting in to the departmental culture getting used to resources and routines. At other times this was a case of managing confidence over time in order to move from observer to teacher within a relatively short period. When under pressure to demonstrate subject knowledge in unfamiliar situations, it is quite natural to draw on personal experience as there are no other frames of reference. As part of the process of adapting to new situations, the establishment of identity as a teacher of the subject was significant. For two the participants felt it was important to have significantly more subject knowledge than the pupils.

#### **4.5. *Placement arena effect***

Another significant aspect from the findings was the placement arena effect on the development of subject knowledge. This was identified by most of the participants at some point during their time in schools. The nature of the specific teaching environment created constraints on what could be taught and consequently what was learned in terms of subject knowledge by both teacher and pupils. The availability of practical resources, for example, instantly framed what outcomes could be produced and to some extent, how they were made. This was further compounded by limitations of staffing expertise across specific material areas where participants sought to further develop their expertise. In one case, the pre-service teacher was working in a placement where it was recognised that they were themselves the most knowledgeable person in their specialism. The way in which the curriculum was interpreted, by departments and individuals, also acted as a constraint on what could

be taught. Given the loosely defined curriculum of Design and Technology it is up to department teams and individuals how they interpret the programme of study and set expectations for pupils.

#### ***4.6. Theoretical and practical***

In relation to specific subject content, there were a number of participants for whom the relationship between theoretical and practical aspects of subject knowledge was of significance for their personal development. In some cases this related to their previous experience when at school or university, where they had been exposed to high levels of theoretical content, and were now faced with the prospect of delivering more practical approaches to the acquisition of subject knowledge. Learning the different ways in which practical skills and knowledge could be taught became the focus for personal development. Combining theory with practice was, for some, expected in both their planning and their teaching.

#### ***4.7. Confidence***

The aspect of confidence emerged in several different ways as a finding from the experience of participants. A number mentioned a lack of confidence with subject knowledge in the early stages of placement. For one of the participants, the lack of confidence related to her recently learned new knowledge. Such was the effect on her confidence that it led to a state of helplessness where she was unable to continue to teach.

#### ***4.8. Working with the new***

One of the features of the placement experience for most of the pre-service teachers was working with the new as they needed to learn new skills and knowledge outside of their previous experience. Even for the experienced craftsperson there are always new challenges when entering new workplace arenas as several participants found out. This was not only within their specialist area but involved working with material areas outside their previous experience. There seemed to be an acceptance from participants that this was not negotiable, rather like being given a job to do. This perception of school as a workplace is reinforced by expectations of professionalism such as punctuality, dress and behaviour. The consequences of such compliance, however, can be feelings of hopelessness. A more pragmatic attitude towards taking on new knowledge was expressed by one of the participants who recognised the limitations of her own experience and the limited extent to her knowledge.

#### ***4.9. Activity***

The development of practical and pedagogical knowledge through activity of different kinds was also a significant aspect of the phenomenon. One of the ways in which participants developed their subject knowledge was through observation and working with pupils during lessons taught by other teachers. This is exemplified in the words of one of the participants who took the opportunity to further her knowledge throughout the course seeking opportunities for observation prior to teaching with new materials.

#### ***4.10. Pedagogy and planning***

Not surprisingly, perhaps, issues of pedagogy and planning were widespread amongst the findings. All participants mentioned pedagogy in at least one of their interviews and, across the whole set of data, this aspect emerged as one of the strongest – appearing in the majority of transcripts. For one participant, the identification of knowledge for teaching was fairly straightforward. This breaking of existing knowledge into digestible chunks for pupils was mentioned by other participants across all stages of the course. Some participants, however, experienced difficulty in deconstructing their existing embodied knowledge into a form that was understandable by pupils in a school environment. Embodied knowledge and taken for granted working practices used by professionals needed to be re-thought in order to be put into a digestible form for pupils.

### **5. CONCLUSION**

There is a need to change the current orthodoxy of subject knowledge as a commodity and to change the ways in which it is conceived within teacher education. This would involve moving from the current focus on audits

and tracking of progress against fixed competences to a positive model that celebrates the ability to develop learning opportunities that involve the use of a range of forms of knowledge by pupils.

The second implication for future practice is in relation to work with pre-service teachers. There is a need to consider how pre-service teachers can be best prepared for adaptation to placement and developing their skills of knowing needs to be an essential component of teacher education. Given the not insignificant effect that the placement experience has on pre-service teachers, both cognitively and emotionally, it will be important in the future to prepare them for the environment in which they will be working. Time spent considering their role and how they will cope with working with a variety of individuals will be a valuable part of their induction to courses.

One of the more challenging issues to have emerged from the study is that of preparing pre-service teachers to learn new knowledge. Creating opportunities for those on future courses to experience learning the new would seem to be an appropriate way of responding to what has been found out through this study.

The third implication for future practice drawn from the study is in relation to working with teachers in placement areas. The study highlights the importance of relationships with teachers and how this can affect knowledge developed. It is important therefore that placement mentors recognise the significance of their role in directing pre-service teachers' knowledge. Both the departmental philosophy about the subject and the interaction with individual mentor have been identified as making a noticeable difference in terms of what knowledge was developed and how it was acquired. Given the current nature of partnership models of teacher education that are school-focused the role of mentors in school to develop the knowledge of individuals will remain a high priority. From the findings and discussion there is clearly much that can be passed on to mentors in terms of the ways in which pre-service teachers have experienced placement and the important role that they play in supporting and developing subject knowledge.

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# Establishing Progressions of Learning in Engineering for High School Students

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While current initiatives in P-12 engineering education are promising, a clear vision and roadmap eludes educators. Little is known about how children progress through engineering learning. Few curricula have explored and investigated how an articulate P-12 engineering program may contribute the general literacy of our children. The *Advancing Excellence in P-12 Engineering Education* project represents a mandate—a call to action—to build a community with a shared focus, vision, and research agenda to ensure that every child is given the opportunity to think, learn, and act like an engineer. This paper will present the first year results of the AEEE project which includes a *Taxonomy of Concepts for Secondary Engineering* and the *Progression of Learning in Engineering* framework for articulating a sequence of knowledge and skills that students are desired to learn as they progress toward engineering literacy.

*Key Words:* Progressions of Learning, Engineering Literacy, Secondary Learning

## 1. INTRODUCTION

The value of engineering in P-12 schools continues to receive greater attention. However, minimal attempts in the United States have been made by the education community to establish the deliberate and coherent study of engineering. Specifically, few efforts have been undertaken to identify developmentally appropriate content and practices for scaffolding the teaching of engineering at the P-12 level. As Reed (2018) states, “engineering is well defined at the postsecondary level but still evolving in PreK-12 education” (p.19). Nevertheless, the uncertainty of how engineering should be taught provides an opportunity for the technology and engineering education (TEE) profession. As no updates have been made to the *Standards for Technological Literacy* (ITEA/ITEEA, 2000/2002/2007) despite adding the word engineering to the profession’s title in 2009, there is a need to address the paucity and rigor of current engineering experiences within P-12 education. Ultimately, this effort can help TEE expand its relevance in the education system, deepen its content and practices, and establish a coherent epistemic basis founded on engineering and design (Strimel, Grubbs, & Wells, 2016).

Consequently, the *Advancing Excellence in P-12 Engineering Education* (AEEE) project was launched to engage experienced teachers and content experts in the development of a taxonomy of engineering concepts and the formation of progressions of learning in engineering for secondary TEE programs. The clear articulation of a progression of learning for engineering concepts can provide a big picture of what is to be learned in high school coursework, support instructional planning for teachers, and act as a guiding framework for locating a student’s current learning status and tracking their process as attempts are made to move their learning forward. This paper will present the preliminary results of the AEEE project which includes both a *Taxonomy of Concepts for Secondary Engineering* and the *Progression of Learning in Engineering* (PLiE)

framework for articulating a sequence of knowledge and skills that students are desired to learn as they progress toward general engineering literacy.

## **2. POSITION OF ENGINEERING IN STEM EDUCATION**

Engineering is a defined field (Reed, 2018) with a long history of development and refinement as a branch of learning at the post-secondary level. Engineering, as a subject, is inherently integrative as it calls upon scientific knowledge, mathematical truths, and technological capabilities to design solutions to societal, economic, and environmental problems. The nature of design in engineering can also enable educators to create accessible, yet authentic contexts for learning. As such, better addressing engineering within TEE may position the school subject to deliver on many of the forgotten promises of the “STEM education movement” while also avoiding several of the stumbling blocks that are a result of the vagaries associated with the “STEM” term. However, much like any STEM initiatives, engineering education cannot be simply adopted by existing programs without careful and informed considerations.

While there have been calls to revise the *Standards for Technological Literacy* (ITEA/ITEEA, 2000/2002/2007) (Reed, 2018)—with some calls requesting the addition of standards for engineering (Moye & Dugger, 2018), a prominent focus in education has become the development of progressions of learning. Progressions of learning are defined as a sequenced set of subskills or bodies of enabling knowledge that students must master to achieve a curriculum target (Popham, 2008). Therefore, progressions of learning will be necessary for the planning and assessment of engineering literacy at the P-12 level. As Marzano (2010) posits, “national and state standards often do not provide guidance in regards to the building blocks necessary to reach the designated learning goals (p.3).” Also, aligning to the work of Fonger et al. (2018), progressions of learning in engineering can serve as a “form of curriculum research that advances a linked understanding of students learning over time through careful articulation of a curricular framework and progression, instructional sequence, assessments, and levels of sophistication in student learning” (p. 30).

Consequently, the authors believe that progressions of learning in engineering can be developed and leveraged in the field of TEE and, if necessary, could potentially inform future standards projects. The authors have purposefully used the term *progression of learning* instead of *learning progression*, as they understand that their work will provide “a progression of learning” and not “the learning progression”. They realize that learning can and will be shaped according to the individualities of students and their communities. The hope is that the initial development will spur the refined and expansion of progressions of learning within and possible beyond the scope present in this paper.

## **3. ADVANCING EXCELLENCE IN P-12 ENGINEERING EDUCATION**

Fittingly, the AEEE project was launched in 2017 to afford leaders, concerned about TEE, a dynamic platform for (a) pursuing a vision/direction for P-12 engineering education, (b) establishing a coherent curricular framework for scaffolding the teaching of engineering and design, and (c) conducting research on the learning of engineering concepts/skills within primary and secondary schools to best achieve engineering literacy for all students. The first objective of the ongoing project was to engage experienced teachers and content experts in the development of a taxonomy of engineering concepts and the formation of PLiEs for secondary TEE programs. To establish the curricular framework and PLiEs, the project has pursued a three-phase method, reinforced by Fonger et al. (2018), which includes Phase 1 research and development, Phase 2 identifying implementation environments, and Phase 3 testing and revision. Each of these phases involve iterative cycles of research, design, and experimentation in order to gather the data necessary to develop validated progressions of learning and assess the effectiveness of the instructional sequences.

## **4. PHASE 1: RESEARCH AND DEVELOPMENT**

Within the research and development phase, the AEEE project team first articulated a vision for a taxonomic structure for engineering concepts and the progressions of learning framework from which they conducted research and development activities to identify and refine agreed upon core and sub concepts for secondary



engineering. This work was then leveraged to establish an instruction sequence for progressions of learning, conducting focus groups for validation, and designing examples for curriculum development using socially relevant and culturally situated learning activities.

#### **4.1. Developing a Taxonomic Structure**

To begin establishing a series of progressions of learning that articulate a depth of understanding from novice to expert in engineering at the P-12 level, the primary components of a viable engineering taxonomic structure had to be established. To do so, the authors sought to identify agreed upon core concepts and sub-concepts of engineering at the secondary level. An initial structure of this taxonomy was founded on the dimensions of engineering literacy (Grubbs, Strimel, & Huffman, 2018) and the synthesis of relevant literature (Carr, Bennett, & Strobel, 2009; Custer & Erekson, 2008; Merrill et al., 2009; NAE, 2009; 2010; Sneider & Rosen, 2009; etc) as well as the National Academies' Taxonomy of Engineering (National Academies of Sciences, Engineering, & Medicine, 2017), the Fundamentals of Engineering Exams (National Council of Examiners for Engineering & Surveying, 2017), first-year engineering programs (Strimel et al., 2018), the Accreditation Board for Engineering and Technology disciplines of engineering, engineering technology, and computing (Engineering Accreditation Commission, 2016), and the ITEEA Engineering Endorsement Responsibility Matrix. Following this work, a modified Delphi study which included experts from the technology and engineering education communities was employed to build a consensus of opinion of the important and viable concepts for engineering at the secondary level. The Delphi method is an approach that seeks to achieve a convergence of opinion on a specific topic by asking experts a round of questions, developing more refined questions that are returned to the respondents, and so on. Accordingly, the experts selected in this study were asked to identify and then rate core concepts and corresponding sub-concepts for both in depth technical elements and cross-cutting fundamental elements of engineering through a total of three rounds (1) Concept discovery (identifying core concepts and sub-concepts), (2) Concept prioritization, and (3) Concept rating. The *Taxonomy of Concepts for Secondary Engineering* is provided in Appendix A.

#### **4.2. Establishing an Instructional Sequence**

The 1st AEEE Symposium provided a platform to complete two crucial AEEE project goals; (1) Stakeholder and expert revisions of the *Taxonomy of Concepts for Secondary Engineering* and (2) establish writing teams and develop preliminary drafts of the PLiEs. To accomplish these goals, the symposium brought together 40 experts from the education, engineering education, technology education, and engineering communities. Experts were invited based on participation from the preceding Delphi study and recommendations from various stakeholders with an interest in the project. Participant selection ensured demographic variety in three primary ways. First was diversity of gender. Of the 40 participants, 19 were female and 21 were male. The second primary demographic was career experience (teacher, engineer, post-secondary). A majority of the participants were active high school teachers (6) or had previous experience as a classroom teacher (15). 19 participants had an engineering undergraduate degree with 11 having industry experience. 15 participants currently hold positions at post-secondary institutions, including colleges/schools of engineering, technology, and education. Many participants crossed several of these demographics. The third characteristic of interest was regional location. As the AEEE project will impact a regionally located school system, participants were sought with a local investment or a national expertise. Participants were organized into four focus groups comprised of at least one high school teacher and one engineer or engineering educator. The groups were then asked to review and revise the core and sub-concepts for each content area based on the following guiding questions:

- Is this a fundamental/technical core concept or sub-concept of engineering? Justify through narrative.
- Is this core concept or sub-concept appropriate for high school learners? Justify through narrative.
- How is this core concept or sub-concept connected to one or more Engineering Skill(s) and/or Engineering Habit(s) of Mind?

Additionally, the focus groups used the progressions of learning framework to draft the PLiEs. The PLiE framework and example progressions of learning are provided in Appendices B, C, and D.

### 4.3. Validation

A series of three focus group studies have been proposed to validate the content organization and PLiEs. In the focus group research design, as described by Krueger (2002), consideration will be given to a) participant selection, b) the environment, c) the moderator, and d) analysis and reporting. The first proposed focus group session (P-12 stakeholders) will look to engage practicing P-12 classroom teachers, administrator, and regional educational stakeholders in various states around United States. The P-12 stakeholder focus groups will leverage state-level teacher organization to recruit participants and identify venues. The driving questions for the P-12 stakeholder focus groups will be; (1) Does the framework for the study of high school engineering align with the goals STEM education? (2) Are the concepts and sub-concepts appropriate for high school learners. The second proposed focus group session (technical stakeholders) will ask technical experts in engineering, engineering technology, and technology to provide comment and refinement on the developed materials. The technical stakeholder focus group will solicit participants from engineering and technical associations and societies (e.g. ASEE, IEEE, ASME). The driving question for the technical stakeholder focus group will be; (1) Does the framework for the study of high school engineering align with the goals of your professional organization and industry? The third proposed focus group session (Engineering Leadership) will seek guidance from engineering administrative leaders from post secondary institution in order to ensure the alignment of secondary engineering with higher education best practices and initiatives. The engineering leadership stakeholders focus group will aim to recruit participants from American Society of Engineering Education Deans Council subcommittee on P-12 engineering education, the National Academy of Engineering, the Order of the Engineer, and the Division of Engineering Education and Centers (EEC) at the National Science Foundation. The driving questions for the engineering leadership stakeholders focus group will be; (1) Does the framework for the study of high school engineering align with the goals the engineering education community?

### 4.4 Curriculum Development

The 2nd AEEE Symposium will specifically focus on the theme of *Equity Through Engineering Curriculum & Pedagogy* and build upon the resulting work from the 1st AEEE Symposium which included a defined *Taxonomy of Concepts for Secondary Engineering* and draft PLiEs. During the 2nd AEEE symposium, participants will hear from national leaders in engineering education, industry, and curriculum development to serve as provocateurs as they work in breakout groups to review and refine the PLiEs and recommend socially relevant and culturally situated engineering instructional vignettes and activities. These materials will serve in supporting the curriculum development team from the schools targeted for implementation.

Engineering education for **all** students requires that equity be at the forefront of any reform effort. Therefore, the AEEE project has taken a mindful approach to ensure that every child is given the opportunity to think, learn, and act like an engineer. The purpose of equity in engineering education does not have to be solely about preparing all students to major in engineering and go on to careers in engineering or technology. Instead, it should be focused on ensuring that all students have the foundational knowledge that will allow them to productively participate in today's world and make informed decisions about their lives. Through culturally situated activities, students can build personal relationships with engineering concepts and practices and ultimately feel like engineering is more relevant to their lives (K-12 Computer Science Framework, 2016).

## 5. PHASE 2: IDENTIFY IMPLEMENTATION ENVIRONMENT

Thoughtful consideration must be given to the characteristics, relationships, and challenges created when implementing research-based, but yet to be classroom refined, curriculum. As outlined below, design-based implementation research can facilitate the testing and revision process. Both practicing teacher and student voice play an important role in design-based implementation research. The establishment of a researcher-teacher partnership can help define the roles of stakeholders that are new or inexperienced in educational research methods who can provide unique and valued input to help guide the research methodologies. Classroom and school partners must be well-positioned to engage in design-based implementation research. As outlined by Coburn, Penuel, and Geil, research-practice partnerships are, “typically long-term, focus on problems of practice, are committed to mutualism, use intentional strategies to foster partnership, and produce original analyses” (p.2, 2013). With concern to the PLiEs, some additional characteristic are appropriate.

Practitioners should be familiar with practices of design-centric pedagogies. Classrooms should provide tools and resources conducive to engineering-type learning experiences, including access and dedicated ideation and design spaces, fabrication facilities with material processing capabilities, and computational tools and programs such as computer workstations, CADD, and MATLAB, among others. Lastly, teacher, administrators, and students of research-practice partnerships should be open to engage in well-informed but still experimental classroom learning experiences.

## **6. PHASE 3: TESTING AND REVISION**

The AEEE project will leverage the work from the first two AEEE Symposia to engage with pilot schools to conduct design-based research for testing and revising the PLiEs. Design-based research (DBR) is an effective methodology for determining how, when, and why an educational intervention works in practice (Design-Based Research Collective, 2003). The design process for the testing and revisions will follow the five characteristics of design-based research described by Wang and Hannafin (2005): (i) Pragmatic. The PLiEs will provide guidance to programs currently being used by school districts and teachers, will directly impact the formation of a high school engineering program of study at large mid-Atlantic school district, and inform various state departments of education. (ii) Grounded. The development and refinement processes will take place within the complexities, dynamics, and limitations of authentic classroom environments. It is anticipated that the constraints of high school culture, climate, and policy will influence the development of the instructional materials. These constraints may include teacher content knowledge, classroom environment, instructional time, and school budgets. (iii) Interactive. The development effort will engage in-service teachers as contributing members of the study. During the yearly project symposia, teachers, project leadership, and content experts will develop engineering lessons, evaluate barriers, field test, and revise the instructional materials based on teacher and student feedback. (iv) Iterative and flexible. As the project is dynamic and on-going, there will be several, but no less than six, feedback revisions/iterations for the instructional materials. Data on the product's effectiveness will be gathered in a variety of quantitative (scales) and qualitative (interviews) methods. The materials will be pilot tested with classroom teachers (yearly symposia), and high school students (curriculum integration pilots). (v) Integrative and contextual. The development process will utilize multiple methods that integrate evidence from several sources, drawing evidence from teachers, students, and other experts. Detailed documentation of each development iteration will consider context. All modifications made to the instructional materials and their implementation will be described through a narrative determining what worked and did not work, how the intervention was improved, and what was the nature of the change.

## **7. CONCLUSION**

In the current STEM-driven educational landscape, it is critical that research and development efforts (e.g. curriculum, teacher preparation, and in-service teacher professional development) are undertaken to better position TEE in school programming. One approach is to continually review the epistemic base for the subject, and ensure it is relevant and distinct (deVries, 2015). The PLiEs address the core theory of knowledge for the TEE subject, while responding to the paucity and clarity of a true engineering education framework at the P-12 level. Moreover, at a time with declining teacher preparation opportunities, and vacancies in the field, the PLiEs serve as a well-vetted guide for implementing rigorous and relevant curricular and instructional activities, directly related to engineering education. As development continues, on-going research will continue to validate the efficacy of each learning progression as it relates to varying demographics, grade levels, and cognitive abilities.

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# Professional Development Program for Teaching Engineering-Focused Curricula in Technology Education

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To respond to the requirement of new technology and engineering talents, many countries have begun to promote engineering-focused programs in science and technology education in primary and secondary schools. How to design an appropriate professional development program for teaching engineering-focused curricula that can be utilized by technology teachers has become an essential issue. By utilizing literature reviews and a focus group, this study intended to explore both content knowledge and pedagogical content knowledge that are required for technology teachers in the implementation of engineering-focused curricula in technology education, and proposed a five-course professional development program accordingly. In addition, the study also conducted a survey among 494 technology teachers in Taiwan to gain an understanding of their degree of acceptance and opinions of the proposed program. The results showed that the majority of the teachers surveyed recognized the necessity of the proposed courses; however, they were not confident in their own knowledge of the corresponding subjects, and were concerned about the problems and difficulties they might encounter in teaching such subjects in the future. The results of this study can provide scholars some insights developed from the professional development program in Taiwan, attract more researchers to participate in the study of professional development of technology teachers, and develop the content knowledge and pedagogical content knowledge required to teach such programs.

*Key Words: Engineering-focused curricula, Professional development program, Technology education.*

## 1. INTRODUCTION

To cultivate 21st century engineering and technology workforces, promoting engineering programs in K-12 schools have been given increasing importance (Daugherty & Custer, 2012; Denson, Kelley, & Wicklein, 2009; Lim, Lee, & Lee, 2014). More and more positioned papers asserted that teaching engineering design in high school has numerous advantages, including the development of students' engineering habits of mind, problem-solving skills, and systems thinking skills (Householder & Hailey, 2012). Although not all students will become engineers or pursue engineering-related occupations, all students can benefit from participating in engineering-design related activities (Wicklein, 2006; Apedoe, Reynolds, Ellefson, & Schunn, 2008; National Academy of Engineering and National Research Council, 2009).

Engineering is a key national resource for Taiwan's competitiveness in a technological-driven global economy, developing engineering content for high school students becomes an imperative approach for recruiting future engineers for Taiwan. Leaders of engineering in Taiwan have called on high schools to look for methods of introducing pre-engineering content into technology education (Ministry of Education of Taiwan, 2016). Technology education is a mandatory course in Taiwan that is focused on technological literacy, and has a history of including design concepts. The recent release of the new technology education curriculum for high school (grades 10-12, age 16-18) marks a significant shift in the core concepts, that is, the adoption of engineering principles and practices into technology education.

Despite the indication of the positive influences from learning engineering on students' academic achievements and intellectual learning (Wicklein, 2006; Householder & Hailey, 2012), high school technology teachers' knowledge, skills, and readiness to teach engineering are limited (Kelley & Wicklein, 2009). In the past, very few technology teachers were taught engineering in their pre-service teacher preparation programs in Taiwan; consequently, the necessity to enhance engineering knowledge is of particular importance. Specifically, this paper explained the development of the professional development program, which enhanced teachers' content knowledge (CK) and pedagogical content knowledge (PCK) of engineering. The researchers approached this goal guided by two research questions: (1) What courses of the professional development program are determined as essential for teachers to teach an engineering-focused curricula? (2) What are the teachers' perceptions on the professional development program in the engineering-focused technology curricula?

## **2. LITERATURE REVIEW**

### ***2.1. Theory of Professional Development for Technology Teachers***

In order to design a professional development program for teaching engineering-focused curricula, it is necessary to identify the required CK and PCK to promote technology teachers' engineering-related teaching knowledge and skills. The effective professional development of engineering-focused curricula design for teachers is needed to increase awareness of the various aspects of the engineering design process (Hsu, Purzer, & Cardella, 2011). Daugherty and Custer (2012) argued that in the development of technology teachers' professional development, it is critical to determine the engineering content of the courses, as well as its related pedagogies, so as to ensure an effective link between the expertise of technology teachers and the students' learning experience. Hynes (2012) examined the teaching of the engineering design process in middle schools from the perspective of teachers' CK and PCK, and suggested that these two types of knowledge should be central to the development of technology teachers' professional engineering knowledge.

### ***2.2. Technology Teachers' Content Knowledge and Pedagogical Content Knowledge in Teaching Engineering-Focused Curricula***

Both CK and PCK should be considered in order to design an effective professional development program for technology teachers. McLaughlin (2002) claimed that, "teachers need to know how to engage students in content knowledge, how to allocate time and attention, [and] how to articulate standards appropriate for practice" (p. 95). Specifically, in order to effectively promote technology teachers' professional development, it is necessary to determine the relevant engineering content that should be taught, as well as the related pedagogies that should be applied.

When identifying technology teachers' CK, Williams (2010) suggested that the core CK of engineering-focused technology education should include engineering design and process enterprises, and the environment and community; in addition, engineering design processes, mechanical engineering, electronica/electrical engineering, and systems and control knowledge should be introduced. Technology teachers are expected to master these four dimensions of knowledge before they are able to teach engineering-focused programs. Meanwhile, the focus should also be placed on the content of national curriculum guideline. The content of the new high-school technology education curriculum includes the following: (1) the nature of technology and engineering, (2) process of engineering design, (3) application of technology and engineering, (4) impact of technology and engineering on society (Ministry of Education of Taiwan, 2016).

PCK refers to teachers' knowledge of transferring subject content into knowledge that can be taught, learned, and understood, including knowledge of educational ends and purposes, curriculum knowledge, knowledge of learners, and knowledge of educational contexts (Shulman, 1987). Knowledge of educational ends and purposes refers to teachers' understanding of the philosophical background, academic values, teaching objectives, and expected results of the subject. Curriculum knowledge is teachers' knowledge regarding "what to teach." Knowledge of learners can help teachers to plan and implement learner-centred instruction, as well as predict the common misconceptions and difficulties of learners. Knowledge of educational contexts refers to teachers' knowledge of the teaching environment and resources. When discussing engineering teaching, and

learning, Dym, Agogino, Eris, Frey and Leifer (2005) argued that applying pedagogical models for project-based learning to cultivate students' engineering design thinking ability is of great significance.

### **3. METHODS**

#### ***3.1. Research design***

The key purpose of this study was to design a professional development program for high school technology teachers to teach engineering-focused curricula in Taiwan. A systematic approach proposed by Custer, Daugherty, Zeng, Westrick and Merrill (2007) was employed in developing the content of engineering-focused technology curricula.

In order to ensure the quality of the professional development program, a focus group was utilized for confirming the CK and PCK of the engineering-focused professional development, and the contents of professional development program in this study. Eight university professors specializing in technology and engineering education and 12 high school technology teachers were invited to serve as experts in the focus group. All professionals provided their comments to the CK and PCK of the engineering-focused professional development, and the content of professional development program. The moderator of the focus group led all professionals to build the consensus and confirm the final content knowledge and pedagogical content knowledge of the engineering-focused professional development, and the content of professional development program.

Moreover, in order to explore technology teachers' perceptions of the proposed program and its course content, a questionnaire survey was utilized for answer research question 2. The validity of this questionnaire was confirmed through the focus group, and the Cronbach's  $\alpha$  reliability coefficient of the five aspects tested was all higher than 0.8. The results of the survey served as an important reference for the promotion of participation from technology teachers in the development of engineering education.

#### ***3.2. Sample***

A purposive sampling method was applied to select 494 high school technology teachers, except the 12 teachers in the focus group, to participate in the questionnaire. As to ensure viewpoints of teachers from various regions, genders, and levels of teaching seniority were collected.

#### ***3.3. Instrument***

The questionnaire utilized in the study was named "Technology Teachers' Acceptance of Professional Development Program for Teaching Engineering-Focused Curricula," which included items related to background information (such as gender, teaching year, and school), acceptance of the content of proposed courses (including course name and content introduction), and open questions designed to collect suggestions for each course. Examples of the questionnaire items are presented in Table 1.

Table 1. Examples of Questionnaire Items for “Introduction to Technology and Engineering”

Introduction to Technology and Engineering	Very Necessary	←	→	Very Unnecessary	
	5	4	3	2	1
<i>Do you think that it is necessary to add this course to the program?</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Key content (1): nature of engineering; basic understanding of engineering related fields; integration of engineering, technology, science, and mathematics and its application; preparation for a career in technology and engineering industries</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Key content (2): Important procedural knowledge of engineering design and application, including: forecast analysis and establishment; testing, correction, and optimization of models/prototypes</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### 3.4. Data Collection and Analysis

First, we defined some key elements that could be included as part of the possible CK and PCK based on the literature review. Next, the draft was presented to the experts in the focus group for assessment and evaluation. Then, suggestions from the experts were collected through audio recordings. Lastly, based on the collected suggestions, the dimensions to be included in the CK and PCK, and the professional development program for teaching engineering-focused curricula were revised. In order to ensure the accuracy of the data analysis and revision, the revised versions were sent to the experts for confirmation, so that the results summarized from the focus group were in line with the experts’ consensus viewpoints.

Moreover, Descriptive statistics were employed for quantitative analysis of the teachers’ background information and levels of acceptance. Furthermore, induction and compilation methods were applied to analyse the qualitative data collected through the open questions. The suggestions from the technology teachers would be adopted as a reference for the promotion of the program.

## 4. RESULTS

### 4.1. Technology Teachers’ Content Knowledge and Pedagogical Content Knowledge

After summarizing the suggestions of the experts, this study proposed the following five dimensions as the complete CK that technology teachers should have, including the nature of engineering, theoretical engineering knowledge, knowledge about engineering, knowledge through engineering, and engineering design and problem-solving processes. The detailed definitions and corresponding content of each dimension are listed in Table 2.



Table 2. The Content Knowledge Required for Technology Teachers

Dimensions	Definition	Core Contents
Nature of Engineering	The basic definition and meaning of engineering, and its relationship with various disciplines, the society, and the environment	<ol style="list-style-type: none"> <li>1. Definition of Engineering</li> <li>2. Nature of Engineering</li> <li>3. System of Engineering</li> <li>4. Development and Evolution of Engineering</li> <li>5. Relationships between Technology, Science, Engineering, and Mathematics</li> <li>6. Relationships between Engineering and the Society and the Environment</li> </ol>
Theoretical Engineering Knowledge	The physical, chemical, mathematical, and other related laws or principles that support engineering systems and product operations (the basic knowledge of scientists and engineers)	<ol style="list-style-type: none"> <li>1. Mechanics</li> <li>2. Mechanisms</li> <li>3. Theory of Structures</li> <li>4. Energy and Power</li> <li>5. Electronics</li> <li>6. Automatic Control Engineering</li> <li>7. Knowledge of New Technology</li> </ol>
Knowledge Through Engineering	The design, practice, and usage related knowledge that universally exists in human activities	<ol style="list-style-type: none"> <li>1. Problem-Solving and Maintenance of Common Engineering Products</li> <li>2. Material Processing Methods and Procedures</li> <li>3. Operation and Use of Common Tools/Equipment</li> </ol>
Engineering Design and Problem-Solving Processes	Knowledge of creative design, engineering design, and problem solving processes, so as to meet practical needs, solve problems, and achieve goals	<ol style="list-style-type: none"> <li>1. Technical Drawings</li> <li>2. Creative Thinking</li> <li>3. Engineering Problem Solving</li> <li>4. Design Thinking/Engineering Design Thinking</li> <li>5. Product Design and Development</li> </ol>

According to the literature review, this study advocated that technology teachers' PCK for teaching engineering courses should focus on the construction of engineering-focused PCK, knowledge of learners, and knowledge of educational contexts. In addition to the pedagogical models of engineering design processes and project-based learning, the participating experts suggested that technology teachers should also be able to apply teaching strategies related to problem-solving skills, creative thinking, and interdisciplinary integration between science, technology, engineering, and mathematics (STEM). According to experts' comments, the PCK that technology teachers should possess is shown in Table 3.

Table 3. Pedagogical Content Knowledge Required by Technology Teachers

Dimensions	Definition	Core Contents
Engineering-Focused Pedagogical Content Knowledge	Teachers' ability to organize, present, and transform specific teaching topics, questions, and content to meet the interests and learning abilities of different students; that is, teachers' knowledge of teaching strategies, teaching pedagogies, presentation methods, and teaching procedures	<ol style="list-style-type: none"> <li>1. Teaching Strategies for Engineering Design Thinking</li> <li>2. Teaching Strategies for Project-Based Learning</li> <li>3. Teaching Strategies for Technological Problem-Solving Skills</li> <li>4. Teaching Strategies for Creative Thinking</li> <li>5. Teaching Strategies for Inter-Disciplinary Integration</li> </ol>
Knowledge of Learners	Teachers' understanding of the characteristics of students, including students' prior knowledge, learning abilities, scholastic aptitude, and misconceptions that students may have towards the topics	<ol style="list-style-type: none"> <li>1. Students' Physical and Mental Development and Corresponding Characteristics</li> <li>2. Prior Knowledge and Abilities of Students at Different Learning Stages</li> <li>3. Students' Personality Traits and Cultural Backgrounds</li> <li>4. Misconceptions of Conceptual Knowledge</li> <li>5. Misconceptions of Procedural Knowledge</li> </ol>

Table 3. Pedagogical Content Knowledge Required by Technology Teachers (continued)

<i>Dimensions</i>	<i>Definition</i>	<i>Core Contents</i>
<i>Knowledge of Educational Contexts</i>	<i>Teachers' knowledge regarding the application of teaching resources, classroom management, and teaching environment planning, and acquisition of educational resources from local communities and the government, as well as understanding the local community and culture</i>	<ol style="list-style-type: none"> <li>1. <i>Design the Classroom for Technology Teaching</i></li> <li>2. <i>Manage the Classroom for Technology Teaching</i></li> <li>3. <i>Industrial Safety and Hygiene</i></li> <li>4. <i>School Characteristics and Local Cultural</i></li> </ol>

#### **4.2. The Content of Professional Development Program**

Based on the dimensions of CK and PCK collected from the focus group, a further discussion was conducted among the experts of the focus group. Then, the following five courses were proposed:

##### *4.2.1. Introduction to Technology and Engineering (2 credits/36 hours)*

The purpose of the course is to reinforce teachers' general knowledge of technology and engineering. The content includes: (a) a basic understanding of the nature of engineering and engineering related fields; (b) integration of science, technology, engineering, and mathematics, and their application; (c) key procedural knowledge related to engineering design processes; and (d) preparation for a career in the technology and engineering industry.

##### *4.2.2. Computer-Aided Design (CAD) and Manufacturing (CAM) (2 credits/36 hours)*

This course aims to improve teachers' CAD- and CAM-related knowledge, and thereby, enable them to apply corresponding technologies in teaching based on students' needs. This course focused on the basic principles, theoretical bases, and application methods of CAD and CAM systems, three-dimensional (3D) drawing techniques, and the management, operation, application, and maintenance of common tools and equipment, such as laser mixers, 3D printers, and three/four-axis computer numeric control (CNC) machines. In addition, the course also integrated important procedural knowledge such as creative design, and engineering design thinking processes and implementation.

##### *4.2.3. Mechanisms and Structures (2 credits/36 hours)*

This course aims to help teachers strengthen their understanding of the principles, knowledge, and applications of mechanical and structural design, so that they are able to design corresponding teaching activities that meet students' needs and requirement of the new national curriculum guidelines. This course includes the following content: mechanical and structural design, engineering materials and their application, product development and production, and application of new technology. In addition, the course also integrated special projects to improve teachers' understanding of the implementation of engineering design, as well as theories related to curriculum development and teaching.

##### *4.2.4. Integration of Mechanics and Electronics, and Control of Mechatronics (2 credits/36 hours)*

This course aims to reinforce teachers' knowledge of the integration of mechanics and electronics, and control of mechatronics, so that they can design corresponding teaching activities according to students' needs. The course covers the introduction of electronic circuit design; the system design and application of microcontrollers (such as Arduino); and the introduction, control, and application of sensors, communication equipment, and technology of electromechanical control. In addition, some special robotic projects (focusing on mechanisms, dynamics, and design of control systems) are included to improve teachers' ability to design projects and corresponding learning activities.

#### 4.2.5. Teaching Methods of Technology and Engineering Courses (2 credits/36 hours)

This course focuses mainly on the teaching strategies of engineering education, so that teachers are able to employ appropriate teaching strategies in designing engineering design related teaching activities, and thereby optimize students' learning performance. The topics covered by the course include teaching strategies for engineering design thinking, design of project-based learning courses and teaching strategies, teaching strategies for inter-disciplinary integration (such as STEM), and teaching strategies for improving problem-solving skills.

#### 4.3. Technology Teachers' Perceptions on the Engineering-Focused Curricula

After the feedback collection from the survey, the technology teachers' acceptance of the five developed courses were analysed. As is shown in Table 4, 74.5% of the teachers agreed that it is necessary to improve their CAD/CAM abilities. In addition, 73.1% of the teachers thought it was important to improve their operation and application abilities of engineering equipment.

Table 4. Computer-Aided Design and Manufacturing

Computer-Aided Design and Manufacturing	Do you think that it is necessary to add these courses to the program?		Core Content			
	N	(%)	Technical drawing ability, combining the application of digital processing equipment such as 3D printers, laser cutters, and CNC systems		Ability to operate and apply digital processing equipment, such as 3D printers, laser cutters, and CNC systems	
	N	(%)	N	(%)	N	(%)
Very Necessary	145	29.4	166	33.6	164	33.2
Necessary	231	46.8	202	40.9	197	39.9
Not Sure	98	19.8	100	20.2	106	21.5
Unnecessary	15	3	17	3.4	17	3.4
Very Unnecessary	5	1	9	1.8	10	2

One explanation for this finding is the prevalence of the Maker Movement in recent years. The emphasis on the ability to “do it yourself” and “problem-solving” is similar to the goal of technology education, and the relevant equipment involved in the movement are also suitable to be applied to technology courses. In addition, the digital processing equipment, such as 3D printing, laser cutting, and CNC systems have developed rapidly over a very short time. Technology teachers' feel the urgency to improve relevant knowledge. Hence, this study proposed that the Computer-Aided Design and Manufacturing courses be classified as elective courses, concentrating on hardware and software tools that are commonly used in technology education, as well as the operation, application, and maintenance of common equipment, so that teachers are able to apply appropriate technologies and equipment to their teaching processes.

Table 5 illustrates teachers' acceptance towards the course, “Integration of Mechanics and Electronics and Control of Mechatronics.” In the survey, 65.6% of the teachers agreed that they need to improve their level of theoretical knowledge of electronic circuits, 67.2% of the teachers believed that they needed to improve program design-related knowledge for microcontrollers (such as Arduino), and 68.8% of the teachers thought it was necessary to enhance their knowledge of the mechanical and electrical components of robots to improve their professional knowledge on the planning and implementation of courses that included robotics projects.

Table 5. Integration of Mechanics and Electronics and Control of Mechatronics

Engineering Design and Teaching: Integration of Mechanics and Electronics and Control of Mechatronics	Do you think that it is necessary to add these courses to the program?		Core Content					
			Introduction to Electronic Circuits, Signals, and Systems		Knowledge and Application of Program Design for Microcontrollers		Design and Implementation of Robotics-Related Projects	
	N	(%)	N	(%)	N	(%)	N	(%)
Very Necessary	141	28.5	130	26.3	143	28.9	161	32.6
Necessary	203	41.1	194	39.3	189	38.3	179	36.2
Not Sure	113	22.9	130	26.3	121	24.5	117	23.7
Unnecessary	28	5.7	30	6.1	30	6.1	26	5.3
Very Unnecessary	9	1.8	10	2	11	2.2	11	2.2

In response to “Mechanism and Structure” (Table 6), 68% of teachers believed that they need to strengthen their knowledge related to principles of mechanical design, 67% of teachers agreed that they should improve knowledge regarding structural design principles, and 66.8% of the teachers thought it was necessary to enhance their professional ability to design and implement engineering-design projects in courses.

Table 6. Mechanism and Structure

Engineering Design and Teaching: Mechanism and Structure	Do you think that it is necessary to add these courses to the program?		Core Content					
			The Principles, Knowledge, and Application of Mechanical Design		The Principles, Knowledge, and Application of Structural Design		Planning and Practice of Engineering Design Courses	
	N	(%)	N	(%)	N	(%)	N	(%)
Very Necessary	126	25.5	122	24.7	121	24.5	138	27.9
Necessary	211	42.7	214	43.3	210	42.5	192	38.9
Not Sure	118	23.9	121	24.5	125	25.3	124	25.1
Unnecessary	33	6.7	31	6.3	32	6.5	34	6.9
Very Unnecessary	6	1.2	6	1.2	6	1.2	6	1.2

It can be seen from Table 7 that the demand for Introduction to Technology and Engineering was generally low, only approximately half of the teachers claimed that the corresponding knowledge was important. According to Table 8, teaching strategies related to problem-solving skill training (reinforcing problem-solving related strategies) had the highest degree of acceptance (63%), followed by teaching strategies of engineering design thinking (57.3%).

Table 7. Introduction to Technology and Engineering

Introduction to Technology and Engineering	Do you think that it is necessary to add these courses to the program?		Core Content			
			Nature of engineering; basic understanding of engineering related fields; integration of engineering, technology, science, and mathematics and its application; preparation for a career in technology and engineering industries		Important procedural knowledge of engineering design and application, such as forecast analysis, and establishment, testing, correction, and optimization of models/prototypes	
	N	(%)	N	(%)	N	(%)
Very Necessary	76	15.4	84	17	88	17.8
Necessary	191	38.7	188	38.1	199	40.3
Not Sure	172	34.8	166	33.6	152	30.8
Unnecessary	46	9.3	48	9.7	46	9.3
Very Unnecessary	9	1.8	8	1.6	9	1.8

Table 8: Teaching Methods of Technology and Engineering Courses

Teaching Methods of Technology and Engineering Courses	Do you think that it is necessary to add these courses to the program?		Core Content							
			Teaching Strategies for Engineering Design Thinking		Course Design and Teaching Strategies for Courses of Project-Based Learning		Teaching Strategies for Inter-Disciplinary Integration		Teaching Strategies for Problem-Solving Skills	
	N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Very Necessary	80	16.2	88	17.8	83	16.8	89	18	107	21.7
Necessary	206	41.7	195	39.5	193	39.1	189	38.3	204	41.3
Not Sure	164	33.2	162	32.8	168	34%	165	33.4	140	28.3
Unnecessary	33	6.7	38	7.7	39	7.9	40	8.1	32	6.5
Very Unnecessary	11	2.2	11	2.2	11	2.2	11	2.2	11	2.2

## 5. DISCUSSION AND CONCLUSION

Responded to research question 1, the professional development program for teaching engineering-focused curricula should provide technology teachers the opportunity to reflect, and redefine the philosophy and value of technology education, so that teachers can truly recognize the value of engineering-focused education and establish a sense of confidence in implementing the new curricula. Historically, technology education has focused primarily on training students' technological literacy, design and problem-solving abilities, and understanding of technology areas such as manufacturing, construction, communication, and transportation (International Technology and Engineering Educators Association [ITEEA], 2007). However, in recent years, some studies have pointed out that such a structure is too broad, and the content of technology courses taught in schools tends to vary greatly thus the value of the subjects is difficult to appreciate (Wicklein, 2004; Wicklein, Smith, & Kim, 2009). To solve this problem, it was proposed to introduce an engineering-focused technology education program in high school level (Asunda & Hill, 2007; Lewis, 2004; Rogers & Rogers, 2005). Although the majority of the teachers in Taiwan also agreed with the transformation of the new curriculum towards more engineering-focused curricula, some teachers argued that such changes might narrow the coverage of technology education and might be too difficult to their students.

Responded to research question 2, in order to help teachers integrate better engineering concepts into technology education, the professional development program for technology teachers is needed in both concept-driven and activity-oriented approaches (Custer et al., 2007). As Avery (2013) recommended, professional development programs should provide exemplar engineering design challenges for teachers to use as a reference model, thus guiding teachers to infuse engineering design principles into traditional classrooms. According to the teachers' feedback from the open question revealed their expectation to have more examples of teaching activities involved in the courses, instead of pure theoretical knowledge. However, it may be interesting to note that even after an effective professional development program has been completed, the teachers' STEM pedagogical contentment, and comfort with teaching STEM, may not be significantly associated with each other (Nadelson, Seifert, Moll, and Coats, 2012). The multifaceted nature of teaching efficacy (teachers' perceptions of teaching engineering-focused curricula and knowledge of the related content) should be carefully addressed to assure growth in teachers' professional abilities. Professional development only takes place through constant theoretical, practical, and reflective engagement with experiences in the classroom, through the broadening and deepening of knowledge towards the construction of new educational beliefs (Engelbrecht & Ankiewicz, 2016).

## 6. CONCLUSION

A priority exists to infuse an engineering-focused curriculum in high-school technology education in Taiwan. In order to approach the educational reform, the preparation of teachers with the ability to implement relevant and high quality, engineering-focused instruction has become vital to these efforts. This study compiled and identified five dimensions of CK and three dimensions of PCK that technology teachers should possess. A five-course professional development program was proposed for teaching engineering-focused curricula. Based on the technology teachers' acceptance towards the proposed program, three major concerns were put forward as following: (1) Teachers are uncertain about the breadth and depth of the content range of engineering-focused curricula; (2) teachers are concerned about the transformation process from the traditional technology education to an engineering-focused curricula; and (3) teachers are worried about their own professional knowledge and ability. It is expected that the findings of this study can provide technology and engineering scholars with further insights based on Taiwan's experience and attract more researches regarding professional development, so that the training of technology teachers can better meet the growing trends and shifts towards such curriculum reforms occurring worldwide.

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# Applying Project Based Learning to Teaching Robotics in Junior-high Schools

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The teaching of robotics has undergone a major change over the last decade. New pedagogic approaches and technologies have been introduced and implemented. One of the most important pedagogic changes was the integration of Project Based Learning - PBL. PBL is a student-centered pedagogy, characterized as an active learning of problem-solving emphasizing teamwork (Mills and Treagust, 2003). In the case of robotics, PBL presents non-trivial dilemmas to students, requiring them to interact (among themselves and the teacher) and collaborate in order to reach a solution. This paper seeks to define the characteristics of the learning process that takes place in the robotics classrooms in junior-high schools. It identifies the factors that enhance and those that undermine the learning, as well as the needs of the teachers to achieve the best results possible. The data have been accumulated using structured questionnaires that included open and closed questions, answered by 176 teachers (N=176). The topics included general attitude, enhancing factors, factors that undermine the teaching of robotics, and the contribution of PBL to both teachers and students. The findings show that as PBL enables the development of an environment that provides an opportunity for equal terms and open discussion between students and teachers. Furthermore, the findings imply that a successful robotics-teaching project requires the participation of the school's management, proper infrastructure, the participation of the students and a major investment by the teacher. The discussion of the findings emphasizes the change that is transforming the role of the teacher (Eacute and Esteve, 2000) from a focus on the provision of knowledge to project management.

*Key Words: PBL-Project Based Learning, Robotics, Project Management.*

## 1. INTRODUCTION

Many investigators and educators mention that some of the conditions under which people learn well, such as what they learn, is personally meaningful to them. What they learn is challenging and they accept the challenge; what they learn is appropriate for their developmental level; they can learn in their own way, have choices, and feel in control; they use what they already know as they construct new knowledge; they have opportunities for social interaction; and they receive helpful feedback. Projects in robotics could afford a good vehicle for implementing the concepts identified above. Indeed, an increasing quantity of literature has reported on the advantages of engaging students in robotics projects to foster their problem-solving, creativity and teamwork skills. Modern robotics construction kits provide opportunities for pupils to design and build interactive artifacts using engineering-oriented instrumentation, including gears, motors and sensors, and to engage in an active inquiry by creating playful experiences.

Countries face the above-presented challenges and demands by devising policies and long-term plans, aiming to provide the required education to both the general population (in the form of Technological Literacy) and the expertise-seeking population (in the form of specialized studies) as part of their formal education (e.g., Del Valle, 1993; Savery & Duffy, 1995; Technology for all Americans, 1996; What Work Requires of Schools, 1991; Williams & Williams, 1997). Immediate implications of these policies are: (a) the need to identify the expected cognitive and learning outcomes for the different populations of learners (Mioduser & Betzer, 2008); and (b) the need to define in curricular and pedagogical terms the way to fulfill the stated goals (e.g., see Kimbell, 1997; Lewis, 1998; Verner & Betzer, 2001; Williams, 2002). The following sections present the cognitive and pedagogical conceptual frameworks that served as background for this study.



Project-based learning is considered by many as a good platform for promoting meaningful learning and fostering higher-order cognitive skills (Blumenfeld et al. 1991; Barak 2012). Projects, according to Thomas (2000), are complex tasks based on challenging questions or problems that involve students in design, problem-solving, decision-making or investigative activities; they give students the opportunity to work relatively autonomously over extended periods of time, and they culminate in Exact sciences products or presentations. Employing the project method in schools, however, is not an easy task for several reasons (Marx et al. 1997): projects often take longer than anticipated; it is hard to let students to work on their own, on the one hand, while maintaining control of the class, on the other; and there is the question of how to integrate the project method into a system that is based generally on formal evaluation and exams. How is it that, despite these difficulties, the project method has become a central ingredient in technology education in Israeli schools, particularly in fields like science and technology (Barak 2007; Mioduser and Betzer 2008)?

## **2. PROJECT-BASED LEARNING IN ROBOTICS**

Project-based learning and problem-based learning (PBL) are often presented as preferred instructional methods for teaching science and developing students' general skills, such as independent learning, problem-solving, creativity, metacognition and teamwork (Savery, 2006; Barak and Zadok, 2009; Kolmos 1996, Thomas, 2000; Crismond, 2011). The PBL environment places learners in an active role where they can cope with authentic assignments and learn through doing design and problem solving while applying knowledge in mathematics, physics, and programming.

Despite the wide consensus in the literature about the advantages of PBL over traditional schooling, educators are increasingly aware of the difficulties and limitations of applying these methods in the regular school context. If the problems presented to students are too well-structured, close-ended or simple, on the one hand, or too abstract or unrealistic, on the other hand, only a little learning is achieved, and students may be busy 'doing' with only little significant learning taking place (Blumenfeld et al., 1991; Barron et al., 1998; Barak, 2013). Booker (2007) uses the term "a roof without walls" to describe the desire to develop higher-order thinking skills (according to Bloom's taxonomy) of children who have not learned facts and gained substantive knowledge in a certain subject. Dolman and his colleagues (Dolman et al., 2005) posit that to stimulate students towards constructive and contextual learning, realistic, open-ended and ill-structured problems must fit with students' prior knowledge. These authors also write that PBL curricula should consist more of tutor guidance at the beginning through the shared guidance of both the students and the tutor, and move to more student guidance at the end. Kirschner, Sweller, and Clark (2006) write about the failure of constructivist-oriented instructional methods such as discovery, problem-based, and inquiry-based teaching because the notion of minimal guidance during learning does not work. Minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process (Hushman and Marely, 2015). The advantage of guidance begins to recede only when learners have the sufficiently high prior knowledge to provide 'internal guidance.' Some supporters of PBL (Hmelo-Silver, 2004, Hmelo-Silver et al., 2007; Savery, 2006) address the limitations of this method, and mention that it is important to tailor the scope and complexity level of the assignments to students' prior knowledge and skills, and provide instruction and scaffolding in order to reduce cognitive load and enable students to learn in a complex domain.

## **3. RESEARCH FIELD**

The study was conducted in junior high schools in Israel, where the teaching of robotics took place in an extracurricular framework, but within the science and technology curriculum. School principals recruited most of the teachers, and some participated in their initiative. Most of the teachers who participated in the program are not science or technology teachers.

## **4. METHODOLOGY**

### ***4.1. Scientific method***

This study is based on quantitative research. The underlying assumption of the quantitative research implies that the best way to understand a phenomena is through a large sample and statistical measurement (N=176). This is based on the belief that focusing on a single example or a limited sample will probably not reflect the entire picture. By using methods and principles of the quantitative research, we established a comprehensive research view and located individual cases.

## 5. RESEARCH QUESTIONS

- What are the differences between educators and professional teachers in their perceptions of the pedagogical contribution of project-based teaching?
- Are there differences in the hierarchical perception of the contribution of a project-based learning that correspond to the teachers' teaching fields?

## 6. RESEARCH METHOD

### 6.1 Participants

The study included 176 robotics teachers in junior high, 43.8% male, and 56.3% female. It is important to note that the teaching subjects of more than half of the teachers who participated in the study (58%) are not directly related to science and technology. About one third (33.5%) of the participants teach engineering, 42% teach humanitarian subjects, and 33.5% teach exact sciences. Half of the participants (50%) have a B.A. degree, 28.4% M.A., five teachers have Ph.D., and the rest have finished high school. About two-thirds of the participants have 1- 4 years seniority in project-based learning, and the rest have more than five and ten years.

## 7. TOOLS

### 7.1 A survey of teachers' attitudes towards teaching robotics

We gathered the numerical data by using a questionnaire that was developed for this research. The goal of the study was to test the attitudes of teachers towards teaching the subject of robotics using project-based learning. The questionnaire included an open questions segment and a closed questions segment in which the participants rated statements on a 6-point Likert scale.

In the segment of competence and satisfaction, two measures were constructed:

**Satisfaction and motivation** - The statements: "I am pleased that I am guiding projects," "I see myself as a facilitator of projects even in five years," and "I will recommend colleagues to participate in these spring projects." In Cronbach's alpha reliability level = 0.844., the average of the satisfaction and motivation found was 4.98, and the standard deviation = 1.09.

**A sense of competence** - The statements: "I have good knowledge in the programming aspect of the robot", "I have good knowledge in the building aspect of the robot," and "I have good knowledge project-based learning". In Cronbach's alpha reliability level = 0.802., the average of the satisfaction and motivation found was 4.22, and the standard deviation = 0.86.

We based the part of the questionnaire that involved assessment of personal contribution to the project, on the theoretical model of Vonk (1995), which divides teachers' contributions into three elements: personal, professional and ecological. Those elements were implemented in the questionnaire as follows:

**Personal** - the statements: how did the project help "the development of your creativity", "your enjoyment of teaching", "your independence in education", and "the improvement of your thinking skills.. Cronbach's alpha reliability = 0.92.

**Professional** - the statements: how did the project help "your professional development", "your knowledge of robotics teaching", "the students participation in the project", "your connection with the students participating in the program", and "creating positive atmosphere in the classroom". Cronbach's alpha reliability = 0.61.

**Ecological** - the statements: how did the project help "to receive roles in the school", "to contribute and increase the sharing of the various subjects of study", "to connect with the parents of the students participating in the project", "to students' knowledge and understanding of other methods of learning", "to the reputation of the school", and "to your relationship with other teachers participating in the program". Cronbach's alpha reliability level = 0.67.

Three general measures were calculated by averaging responses to the indicators included in each category. To test the distinctive validity of the three groups, we figured Pearson adapters between the three. High positive correlation coefficients of medium intensity ranging from 0.50 to 0.75 were found, indicating that the three categories are interrelated, but each has a unique meaning.

## **8. RESULTS**

### ***8.1 Ability and satisfaction***

#### *8.1.1. Comparison between educators and professional teachers*

To examine the difference between educators and professional teachers' perception of their ability to lead a project and the sense of satisfaction due to this ability, we conducted a T-test for independent samples comparing the two groups. A high level of satisfaction was found among educators (M=4.71, standard deviation = 1.24) and among professional teachers (M= 5.03, standard deviation = 0.97). According to the findings, there was no significant difference between the two groups.

We found a high level of perception of their ability to guide projects among educators (M=4.35, Std. D=0.89) and professional teachers (M= 4.13 ,Std. D=0.89). According to the findings, there was no significant difference between the two groups.

#### *8.1.2. Comparison of teachers from three teaching fields*

A one-way analysis was conducted comparing teachers in three fields - Social Sciences, exact sciences, and engineering - regarding the teacher's perception of their ability and satisfaction. There were no significant differences between the three groups.

### ***8.2 Technological Areas***

To examine whether there is a difference between educators and professional teachers regarding their perception of the contribution of three-dimensional project-based teaching, we conducted a bi-directional analysis: group (educators, professional teachers), and type of contribution (ecological, personal, professional). The "contribution type" variable was repeated.

A significant effect was found on the role of school teachers in perceiving their contribution ( $F(1,173) = 5.70, p < .02$ ) which stems from the fact that educators view their contribution to the project (M= 5.00, Std. D= 0.68) much more than professional teachers (M= 4.72, Std. D= 0.72).

In addition, a significant effect of the type of contribution ( $F(2,346) = 5.178, p < .001$ ) to the perceived personal input. To examine the sources of the differences between the personal contributions, we conducted a Bonferroni-type postural test, which showed the contribution (M= 4.99. Std. D= 1.07). The professional contribution (M = 5.01, Std. D= 0.90) was perceived as significantly more significant than the ecological contribution (M= 4.42, Std. D=0.79). Whereas between the personal and the professional contribution no significant difference was found. The effect of role-role interaction and the type of contribution ( $F(2,346) = 2.72, p < .06$ ). The averages of the degree of personal contribution by role in education and the type of contribution, are presented in Figure 1.

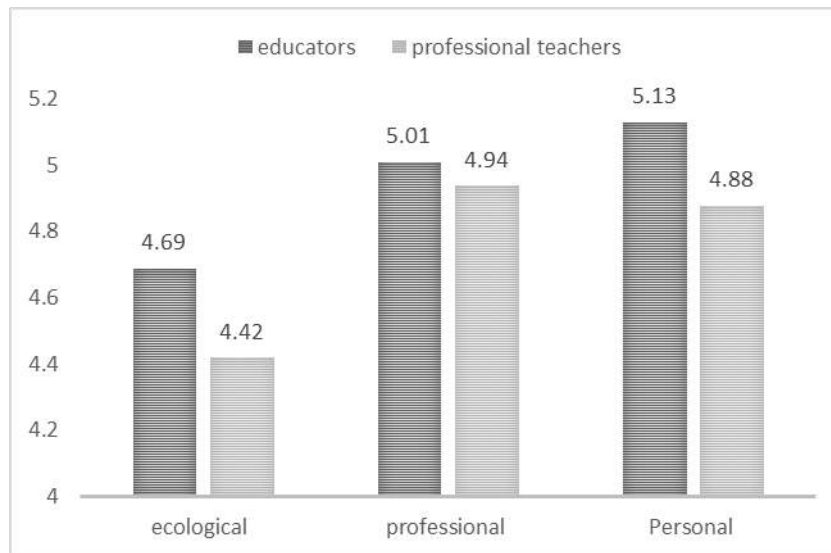


Figure 1. Averages of personal contribution by education and type of contribution

The T-tests between the two groups and the chart above show that the significant difference between the professional teachers relates to the ecological aspect ( $t(173) = 3.83$ ,  $p < .001$ ). The difference relating to the other aspects was not significant. To examine whether there are differences between teachers' perception of the professions hierarchy we conducted bi-directional analysis, subjects group (Social Sciences, science, engineering) and X as the type of input (ecological, personal, and professional). The "contribution type" variable was repeated. Table 1 below presents the averages and standard deviations of the perception of contribution by group and type of contribution.

Table 1. Averages and standard deviations of the perception of contribution by group and type of contribution.

	Ecological	Personal	Professional	Total
Social Sciences	4.62 (0.70)	5.08 (1.00)	5.05 (0.91)	4.90 (0.66)
Exact Sciences	4.55 (0.88)	5.06 (1.28)	5.09 (0.10)	4.92 (0.87)
Engineering	4.10 (0.74)	4.82 (0.98)	4.90 (0.73)	4.67 (0.62)
Total	4.43 (0.79)	4.99 (1.07)	5.01 (0.90)	4.84 (0.71)

In the analysis, the effect of teaching fields was close to contagion ( $F(2,173) = 2.82$ ,  $p < .06$ ). The table shows that teachers in the humanities and non-profit fields perceive the contribution as higher than that of engineering teachers. No significant difference was found as to the interaction between teaching and contribution.

## 9. CONCLUSION

The satisfaction and motivation of teachers who participated in the study regarding project placement are high, the systemic aspects are perceived as promoting the success of the project at a fairly high level, the knowledge of instruction and programming is at a medium-high level, and programming knowledge is at a medium level. As for the personal characteristics of the teachers, it was found that the systemic aspects were perceived as promoting the success of veteran teachers in guiding projects and among teachers who underwent training. In addition, professional knowledge is perceived to be higher among teachers who underwent advanced studies and among teachers who graduated higher education. Finally, it was found that veteran teachers at the school showed greater satisfaction and motivation than less veteran teachers.

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# Toward an Understanding of Dysgraphia as a Barrier to STEM-Related Careers

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Drawing and sketching require the close interaction and coordination of psychomotor and biomechanical processes with developmental, learning, and maturational processes to perform the complex and fine motor behaviors of these activities. Dysgraphia is a learning disability that directly impacts a student's ability to perform these tasks proficiently, if at all. There exists a paucity of research into the effect of this learning disability on the science, technology, engineering, and mathematics (STEM) educational and career interests and pursuits of the students affected by this and related reading and writing impairments. Although dysgraphia is literally interpreted as "bad writing," it also affects a person's ability to visualize and draw lines and shapes. STEM subject matter and activities often involve drawing and sketching, and that the ability to transfer mental imagery to paper and vice-versa is a predictor of STEM education and career success. Given this, there may exist a population of students who are being overlooked and would benefit from a better understanding of the condition by educators and potential interventions that can be researched to engage these students within STEM disciplines. This paper will explore this learning disability as it exists in STEM education through a narrative case study involving a student currently enrolled in an engineering program. This case study is designed to understand the condition of dysgraphia and the barriers to STEM education as perceived and experienced by a student successfully mitigating these barriers through assistive technologies, self-advocacy, and teacher awareness. This paper is meant to raise awareness of the condition in our field and serve as a starting point in the literature where this topic currently represents a dearth of the academic discourse surrounding special education in STEM.

*Key Words: Dysgraphia, STEM Careers, Technology Education, Educational Technology, Barriers to Education, Engineering Graphics.*

## 1. INTRODUCTION

Sketching and drawing are critical components of many science, technology, engineering, and mathematics (STEM) curricula. The ability to quickly sketch, label, annotate, and dimension freehand drawings is part of the engineering design process and crucial to the ideation, externalization, and communication of ideas, concepts, and designs throughout both the education and career domains of STEM professionals. They are especially relevant to those in technology and engineering disciplines where design and problem solving are prevalent.

Sketching has been demonstrated to help designers with handling abstraction, the understanding of ill-defined problems, enhancing problem-solving, and aiding in communication (Booth, Taborda, Ramani, & Reid, 2015). Even with the comprehensive adoption of computer-aided design (CAD) software packages in secondary and post-secondary technology and engineering programs, sketching remains a widely used and required component of coursework in these areas. A recent study found 61% of university-level engineering courses include sketching as a component (Martin-Erro, Dominquez, & Espinosa, 2016). The ability to sketch three-dimensional objects is also identified as a significant factor in the development of spatial skills which is a significant predictor of success in engineering graphics coursework and student persistence through an engineering degree (Ernst, Williams, Kelly, & Clark, 2017; Sorby, 1999).

Given the importance of sketching and drawing to technology and engineering curricular pathways—and ultimately career choice—understanding barriers to sketching ability is essential if they are to be mitigated by instructors and curricula designers. This is especially imperative if there is a goal of broader diversity and inclusion within STEM disciplines. This paper focuses on one such barrier, dysgraphia, by examining the perceptions, attitude, and experiences of a student diagnosed with the condition who is successfully navigating an engineering program. It is our hope that the student’s experiences will shed light on an issue that is currently not addressed in the literature within the contexts of engineering, engineering graphics, or technology education programs.

## 2. DYSGRAPHIA

Dysgraphia is identified as a specific learning disorder under the rubric of developmental coordination disorder by the American Psychiatric Association (2013). Generally discussed in contemporary literature within the context of handwriting and spelling, dysgraphia literally translates to difficult (*dys-*, *English*) writing (*-graphia*, *Greek*). Viewed largely as a handwriting impairment, dysgraphia also affects a person’s ability to draw lines and shapes. The condition represents a neurocognitive disorder associated with executive functioning and fine-motor and visual-motor deficits (Mayes, Breaux, Calhoun, & Frye, 2017).

The symptoms of dysgraphia are often overlooked by educators, and students with the condition are viewed as unmotivated or uncaring (Berniger & Wolf, 2009). Beyond poor handwriting, students with dysgraphia will display symptoms such as displayed in Figure 1. Students will not exhibit all of the symptoms listed but must display a number of them, although how many or the frequency of observation is unclear.

- Cramping of fingers while writing short entries
- Odd wrist, arm, body, or paper orientations such as bending an arm into an L shape
- Excessive erasures
- Mixed upper case and lower-case letters
- Inconsistent form and size of letters or unfinished letters
- Misuse of lines and margins
- Inefficient speed of copying
- Inattentiveness over details when writing
- Frequent need of verbal cues
- Relies heavily on vision to write
- Difficulty visualizing letter formation beforehand
- Poor legibility
- Poor spatial planning on paper
- Difficulty writing and thinking at the same time (creative writing, taking notes)
- Handwriting abilities that may interfere with spelling and written composition
- Difficulty understanding homophones and what spelling to use
- Having a hard time translating ideas to writing, sometimes using the wrong words altogether
- May feel pain while writing (cramps in fingers, wrist and palms)

*Figure 1: Potential signs and symptoms of dysgraphia (Berniger & Wolf, 2009)*

Dysgraphia interferes with students’ ability to learn, complete coursework, communicate, record ideas, demonstrate knowledge, and keep up with peers and teacher instruction. This interference can also create or exacerbate deficits in emotional, academic, and social development and affect factors related to educational motivation, achievement, and persistence such as a self-efficacy, self-esteem, anxiety, and depression in students (Berniger & Wolf, 2009; Martins, et al., 2013). What needs to be very clear is that dysgraphia is a psychomotor disorder involving neurocognitive function and does not affect cognitive functioning, nor is it recognized as a cognitive impairment.

There exists a dearth of study into dysgraphia that is explicitly acknowledged in psychologic and neurocognitive literature, which may account for dysgraphia’s categorization as a specific learning disability (APA, 2013; Mayes, et al., 2017; Nicolson & Fawcett, 2011). Dysgraphia also shares high levels of comorbidity with dyslexia, attention deficit hyperactivity disorder (ADHD), and developmental coordination disorder which, coupled with a lack of assessment specific to dysgraphia, make determining the percentage of students with dysgraphia difficult to ascertain (Mayes, et al., 2017). Reynolds (2007) estimated the prevalence

of dysgraphia to be 5-20% depending on the grade level, but there is a general lack of clarity and consensus in the literature.

Sketching requires a person to take what exists in the mind's eye and transfer that image to the hand to draw it and view/evaluate the resultant illustration through the eyes and back to the brain. The same process of orthographic coding and sequencing occurs when a person writes (Berniger & May, 2011). Dysgraphia disrupts this loop resulting in malformed lines and representations of letters and images stored in the mind's eye. Although the drawing of shapes is mentioned in the literature and the drawing of geometric shapes is part of a diagnostic assessment for dysgraphia (Mayes, et al., 2017), the focus in the literature primarily focuses on the writing ability of the subjects. Provided the requirement for orthographic and pictorial drawing and sketching in engineering and technology education, this paper seeks to examine the impact of dysgraphia in that setting.

### **3. METHODS**

This research used a narrative case study approach to collect in rich detail and analyze the account of one engineering student, Nick, to understand the condition of dysgraphia and the barriers to STEM education as perceived and experienced by a student successfully mitigating these challenges. Narrative research explores how people make meaning of their experiences through storytelling. To accomplish this, the authors interviewed a current engineering student in an attempt to co-construct the student's story using a thematic approach. The interview was transcribed and reviewed for emergent ideas using Clandinin and Connelly's (2000) three-dimensional inquiry space model. Patterns were identified and described in a chronological manner and the larger meaning of the story was interpreted.

#### **3.1 Interview**

The authors met with Nick in a restaurant near campus for 2.5 hours. The first hour was spent getting to know the student generally. The following 1.5 hours was filled with a semi-structured interview format that included a list of questions, as well as the freedom to probe additional topics as they arose.

#### **3.2 Themes**

Five overarching themes developed from the interview: 1) how dysgraphia makes Nick feel different, 2) campus disability services offices, 3) barriers created by dysgraphia, 4) assistive technology and tools that help mitigate dysgraphia, and 5) the impacts of dysgraphia on achievement in an introductory engineering graphics course. For this paper, some elements of the themes have been combined due to space constraints.

#### **3.4 Context**

The engineering graphics course is required for nearly all students majoring in engineering, graphic communications, and technology education degree programs. The course is taught in large sections (~60 students) and uses a hybrid instructional format where a large percentage of the content is stored online. Students are required to watch videos and practice the lessons from class at home. Much of the class time is dedicated to lectures on graphics theory and sketching practice. CAD is a major component of engineering graphics and is the subject of many of the online videos. The majority of the CAD work and instruction is done outside of class.

Nearly half of all graded assignments in the course involve hand sketching (not including required classwork), 40% of the midterm exam grade is a hand-drawn orthographic projection and isometric representation of an object, and the final project requires a drawn technical sketch. Students are also required to annotate engineering drawings and fill in a required title block that must be done in uppercase single-stroke century gothic font with required size and spacing according to international engineering standards. Additionally, this course relies heavily on the design process which is generally taught with sketching as a requirement of the ideation and refinement components of the process.



## 4. NICK'S STORY

### 4.1 Background

Nick presents himself as clean-cut, friendly, bright, and expressive. Now a 20-year-old junior at a large research university in the southeastern United States well known for engineering, he is quick to recall the struggles of his childhood. The symptoms of dyslexia and dysgraphia became apparent around the age of 2 to his mother who has studied special education in college. Extensive testing followed from ages 3 to 10 to determine the extent of his condition. Nick was required to do training exercises several times a week that consisted of everything from how to hold a pencil and handwriting letters set to music for rhythm to reading speed and comprehension. He noted the diagnosis was not a complete surprise; his father has dyslexia and it is genetic. It was because of dyslexia that his father avoided going into a STEM field like he wanted because he was unable to read the amount of material required. Instead, he is an artist at an advertising firm.

Nick's mother homeschooled him through middle school, except for one year when he was about 10. He went to a private school for a year but didn't like it because the teachers and administration did not know how to handle his disability. Beginning at age 9, Nick was able to attend several engineering camps, including competing in the First Lego League. These experiences led him to be "dead set on being in software programming" around age 15.

A local community college near his home offered a program called Career and College Promise that concurrently enrolled high school students in community college courses. Nick completed the minimum 30 required hours and earned an associate in science degree. By this time, Nick realized he was familiar with several areas of engineering and wanted to be a project manager so he could combine everything. He selected mechanical engineering as a major because he felt it was general enough to shift into overseeing other areas.

It was from 9th to 11th grade when he says he better came to terms with dysgraphia:

Things started to click more in regards to dysgraphia specifically, um, because I had – there were moments where I was like, "Ok, how do I combat this? Like, how do I just avoid it?" Because half of me was like I want to fix it; the other half was like I just want to get around it. So, fixing it was doing those really weird pen exercises. Getting around it was typing. And then also I learned how to use CAD by the time I was 13.

### 4.2 Being Different than Other Students

Reading and using his hands for writing or sketching is a challenge. Nick tries to shake out the muscles in his hand when he has to write out math notes. He likened dysgraphia to,

micro-arthritis, and basically causes your hands to be slightly weaker, and it's basically like the muscle memory not fully forming. So like whenever I'm writing, there will just be like moments when I'm like, "Oh man, I can't write anymore." I mean some people will just be like they like to write in journals all day long. After like a certain amount of notes, I'm like, "I'm tapped out. This hand is done. It cannot write anymore."

Nick has to approach learning differently than his peers. He didn't take the Scholastic Aptitude Test (SAT), which is used in the U.S. as a measure of college preparedness in math, writing, and reading, because the accommodations he would need would have made it a three-day endeavor. He cringed as he recalled the embarrassment of having someone read him the driver's permit test because there wasn't a computer reader available. He didn't read for pleasure like many teens but had audio books instead. In middle school, he was two math levels ahead of grade level, but in remedial reading classes:

Cuz it definitely makes me kind of feel—it makes me feel different. That's a major, critical point. Whenever I see like, uh, someone that has, like that doesn't have it, it's...one, I always dream I was in that situation, simply because I've never had a moment where I've ever picked up a random book...

### 4.3 Barriers

Simply put, dysgraphia makes it so Nick doesn't have 100% control over his hand movements. He describes his fine motor control is "slowish," but laughed as he said, "I can game totally fine." He notes he is great at welding and good at soldering and getting better. His hand has a slight shake to it:

Most people with dysgraphia can write to the same level as someone without dysgraphia. It might just take us a second more. Speed isn't exactly our greatest forte, especially with handwriting or drawing. It's not, like, we're typically good about accuracy if we're able to reset and erase, basically. Like on the first try, first draft, will never work. Like if I was to like hand sketch something, like try to draw a straight line, almost certainly, it's going to be curvy. Like, without a doubt.

The combination of dyslexia and dysgraphia creates a much more extensive cognitive load:

It's strictly based on if I know how to spell it [the word he is writing]. And that's where the dyslexia starts to come. If I know how to spell it, I can spend more time thinking about it [writing]. If I have to think on how to spell it, I have to spend more time thinking about it and not caring how my hand works.

I can hear the word I know I want to say, cuz like every word for me is auditory, so I'm like when I hear them say it, I will like immediately know what I need to say, but the moment that I'm going into writing, I'm like that's not what I want. Like, I know it should be this way and then there will be a moment when I'm just like, 'Why am I writing an S? I'm supposed to be writing an A. That's not even close.' It's like a disconnect.

#### ***4.4 Assistive Technology and Tools***

Audiobooks, text readers, and typing have been Nick's saving grace. He has software on his laptop, phone, and tablet that will read documents to him. "It stops being like a disability and more just like it's a different way of doing," he said. He is able to type his notes, rather than handwrite them. If a professor writes on the board, he can snap a photo with his phone. He can even request someone to take notes for him through the university's Disability Services Office, but he feels he would rather go to class and "suffer through it" to "slowly understand it." For in-class "emergencies" like a pop quiz, Nick has a C-Pen Reader Pen that can read the text to him.

He likes sketching with Photoshop and a stylus pen due to the ease of erasing. He uses CAD programs such as SolidWorks, PTC Creo, and AutoDesk as his "cheap way of combatting hand-drawn sketches." Nick notes CAD is an equalizer; he only needs to think about the item he needs to draw rather than all the details. The software allows him to make a straight line so he can focus on the relationships instead. However, even low-tech tools like grid paper, rulers, mechanical pencils, erasers are crucial. "There isn't a whole lot of dysgraphia technology given the fact that the more we push into the digital age, the more it is just kinda getting fixed on its own," he said. Typing was the way he "could figure out dysgraphia."

#### ***4.5 Impacts on Engineering Graphics***

Engineering graphics is hardest for him when doing free sketching without grid paper. Between the ages of 12 and 16, Nick used grid paper for all his writing to help with the dysgraphia. He'd write reports and math on it before he transitioned to typing:

If you were to give me a sheet of paper right now with no lines on it and tell me to draw a square, I will guarantee it will look like a slightly angled rectangle because one side will almost certainly be longer. I don't know which side. I typically have a good start and a bad finish. Basically, the more, the more, I do the worse it gets... But, if we're in the land of CAD, that knocks it out completely. Because at that point, it completely cancels the disability.

Nick's hand sketching is relatively good now because of all the exercises at a young age. He explained he feels the force of his hand trying to cause something to happen, but it doesn't turn out the way he intends it. The disconnect is recognizable as it is happening because of extensive training. Nick said isometric drawings come naturally, but he can do circles and curves better than isometric, which is usually not the case for most people. He can visualize the 3D shape as he's drawing it because he can use his other senses to help him rotate objects, but staying on the line can be hard. Multi-view drawing is harder because drawing a straight line is difficult. Free-hand sketching, such as modeling a block, is challenging because he has no sense of scale:

Getting it from your head to the paper, that is the difficulty. Cuz trying to basically turn whatever you have in your head. Cuz, like, dyslexia allows me to manipulate objects, but then turning it into my hand, there's, like, a miscommunication. Like, I want it to do that, it just doesn't."

Despite these challenges, Nick admits he misses more points in classes when he doesn't get dyslexia assistance and reads it wrong. Had a 3.9 GPA in community college. He now has a 3.7 but wants it to be a 4.0. He has only lost a few points in engineering graphics so far because he is missing a line or for line quality. He explained dyslexia affects the grade; dysgraphia affects him when he doesn't know how to prepare.

Interestingly, Nick believes kids with dyslexia gravitate to engineering because “it is a different way of thinking.” Those with dysgraphia tend to want to be in software or electrical engineering. If students are diagnosed with dysgraphia when they are young, he said they can find ways to deal with it. “It will get better. Don’t get discouraged,” he advised.

## 5. DISCUSSION/CONCLUSION

Nick’s experience with dysgraphia is consistent with the contemporary literature related to the disorder in educational contexts. His insight offers a glimpse into how students with dysgraphia may experience technology or engineering courses where sketching and drawing are prevalent. We acknowledge that Nick is but one student in one course at a particular university and that his experience may not represent the experiences of other students with dysgraphia in similar courses. We are also limited by the format of this paper and further expansion of the analysis and a greater review of the literature are necessary to provide a clearer picture of the disorder and offer possible research avenues to potentially develop interventions and teacher professional development to better the educational experience and outcomes of students like Nick.

For Nick, it is clear that dysgraphia presents barriers to learning and persisting in STEM education. However, there are methods by which those barriers can be mitigated through technology, support, and awareness. Since an accounting of the proportion of students with dysgraphia is lacking, we don’t know the extent to which students may be impacted in our courses and in STEM pathways prior to university matriculation. It is conceivable through further exploration of this case and a broadening of the scope of study, we may work to mitigate barriers for other students and increase the number of students interested in STEM that would otherwise be turned off.

*We would like to acknowledge Nick for his assistance and cooperation in this research study and thank him for so openly sharing his experiences.*

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# Using a problem solving toolkit – in an international distance learning course

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The in2it Erasmus+ project aims to develop and implement an innovative technological infrastructure for the purpose of advancing internationalization in higher education to strengthen the capacities for teaching, learning, research and training. Seven EU universities and seven Israeli colleges collaborated in this mission to develop four international courses (<http://braude.ac.il/in2it/>). The courses are: Global Entrepreneurship, Essential Skills, Embracing Diversity, and English for Internationalization Purposes. This paper focuses on the ‘essential skills’ course in which 110 students from various institutions participated. Eleven faculty members developed the course over a year, while holding consortium meetings via Skype and BBB and working on collaborative files. ‘Soft skills’ are related to 21st century skills that are essential for success in today’s world in general, and in the workplace in particular (Seery et al., 2016). In contrast, the term ‘hard skills’ is usually used to describe profession-specific skills. Many employers report that entry-level employees in a variety of professions lack the soft skills essential for businesses to move forward. From the outset, we decide to focus on the skills of: reflective thinking, teamwork, personal leadership, creative thinking, and problem solving. The problem-solving module is based on the concept of using a problem-solving toolkit rather than linear problem-solving stages (Mioduser, 1998; Mioduser & Dagan, 2007). The problem-solving toolkit encourages the students to choose the order of using the tools and to use each tool more than once during the problem-solving process as opposed using a linear problem-solving stages. The module is divided into two sections: 1) individual – studying the problem-solving toolkit and 2) collaborative – solving a problem while using the toolkit, in international teams. This paper describes using a problem-solving toolkit in an online Essential Skills international distance-learning course that developed through the In2it Erasmus+ project.

*Key words: Problem solving, Soft Skills, Teamwork, International teams, Collaboration, E-learning course, Higher education*

## 1. INTRODUCTION

IN2IT project is an Erasmus+ project. Its aims are to develop and implement an innovative technological infrastructure for advancing internationalization in higher education, and thereby to strengthen the capacities for teaching, learning, research, and training and to improve the quality of Israeli academic colleges.

In the current era of globalization, internationalization in HEIs (Higher Education Institutions) contributes to the development of students’ skills and employability in the 21st century. Project IN2IT aspires to exploit available ICT to advance internationalization and make it accessible to all global citizens, in class and at home.

The IN2IT consortium consists of seven Israeli colleges and seven European universities (about IN2IT and its partners see: <http://braude.ac.il/in2it/about/overview/>). The collaboration of Israeli colleges with EU universities, creates a unique opportunity for the development and implementation of an advanced, state-of-the-art, sustainable technological platform for internationalization in higher education that will create a competitive advantage for colleges in Israel.

Four courses (Global Entrepreneurship, Essential Skills (ES), Embracing Diversity, and English for Internationalization Purposes) were chosen from many subjects suggested by the HEIs. Each of the courses was developed through the collaboration of an international team. Over a year, the developers met each other in

face-to-face consortium meetings and via on-line synchronous meetings. All four courses were delivered to students during this academic year, with around 500 students participating in them.

At the start of the Essential Skills (ES) course development, five soft skills were chosen from the 22 that are considered very important skills: critical and reflective thinking, teamwork, personal leadership, creative thinking, and problem solving. The developers' team decided together on the general aspects of the course and five sub-groups of experts developed each module (skill) of the course.

At that time, a short pilot was developed and delivered to a group of four students from each institution (n=36). The pilot focused on the teamwork module. International teamwork and few ICT solutions were tested. The conclusions from the pilot were integrated to the developed course. A course site was developed on the MOODLE platform.

The ES course emphasises the importance of: a) studying how to use the five ES that were chosen; b) internationalization – the collaborative activities between the European and Israeli students and c) innovative technology – the use of innovative technology to support the pedagogical aims.

Assessment of the students' learning outcomes was based on a student portfolio put together during the learning process, each assignment being saved in the student's personal portfolio. Assessment criteria (rubrics) were formulated for each task.

Problem solving (PS) skill is located as the last skill taught at the end of the ES course, as the students can implement the previously taught skills while solving the problem. The method chosen for teaching PS is the toolkit (functional method) as a continuation of what was found in the research of Mioduser & Dagan (2007).

## **2. THEORETICAL BACKGROUND**

The theoretical background will focus on: a) 21st century skills; b) soft skills; c) problem solving and d) on-line learning at HEIs.

### ***2.1. 21st century skills***

Growing numbers of business leaders, politicians and educators are united around the idea that students need 21st century skills to be successful today. Those skills were important before, but now collective and individual success depends on possessing them (Rotherham, & Willingham, 2010; Dede, 2010). The OECD (Ananiadou, & Claro, 2009) identified three dimensions of those skills: a) information - research and problem solving; b) communication - effective communication and collaboration and virtual interactions; and c) ethics and social impact. The Israeli national program "Preparing the education system for the 21st century" started in 2010, identified similar skills (MOE, 2011).

### ***2.2. Soft skills***

"Soft skills are closely related to what are described as 21st century skills - a broad set of knowledge, skills, work habits, and personal traits that are considered highly important for success in today's world, especially in modern workplace settings" (Seery et al. 2016). Soft skills have also been defined as a dynamic combination of cognitive meta-cognitive, interpersonal, intellectual and practical skills (Haselberger, Oberhuemer, Perez, Cinque, & Capasso, 2014). "Soft skills" refer to a cluster of personal qualities, habits, attitudes, and social graces that make someone a good employee and compatible to work with. Companies value soft skills because research suggests and experience shows that they can be just as important an indicator of job performance as hard skills (Lorenz, 2014). We distinguish these skills from the "hard skills" needed for a specific workplace.

The ModES project (Haselberger et al., 2014) identifies 22 soft skills and clusters them into three groups: personal, content-reliant/methodological, and social. In this project, each soft skill is defined and associated with other soft skills. It demonstrates that the relationships between individual soft skills create complex structures.

In the GRASS project, Seery et al. (2016) divided the soft skills to the following four categories: a) Ways of working (Intra–personal development); b) Ways of working with others (Inter–social participation); c) Ways of thinking (Intra–personal development); and d) Ways of thinking with others (Inter–social participation).

Soft skills are usually offered only to managers in industry and rarely in HEIs. Industry demands that graduates will have such soft skills when they enter the work place.

In the IN2IT ES course, it was decided to focus on five skills that are very important for industry and as academic skills as well: Critical and reflective thinking (ways of thinking), Teamwork (ways of working with others), Personal leadership (Ways of working), Creative thinking (ways of thinking) and Problem Solving (ways of thinking with others) (Seery et al., 2016). The focus of this paper is the method that we chose for teaching and learning the skill of problem solving.

### **2.3. Problem solving (PS)**

Each PS process begins with a gap between an existing state and a desirable one. While teaching PS we would like to improve the learners' cognitive skills and their internal representations. By internal representation, we mean the cognitive constructs that store declarative and procedural knowledge, and a person's mental models of solving ill-defined problems, phenomena and systems (Mioduser, 1988). While conceptualize problem solving, Delahunty et al. (2013) indicated two processes: analysis of the problem and synthesis of the solution. They showed from their research that only few students have the ability to transfer knowledge from a previously learned context and use it in a new type of task, and this is at the heart of effective problem solving.

Over the years, studies have identified two methods for problem solving: a) the algorithmic approach - identifying logical paths that bring us to possible solutions (Polia, 1957;) and b) the heuristics approach – identifying the ability to improvise solutions to a stimulus an “Artistic” ability to create ideas (Schon, 1983; Hegaty, 1991). The classical view is that PS frames internal representations, and these representations can be distributed over internal and external structures. PS as a subject works from an initial state with mental support, actively constructing possible solution paths, evaluating them and heuristically choosing the best. The control of this process is not well understood, as it is not systematic (Kirsh, 2009). In contrast, situated cognition does not have theory of PS. From this perspective, problems do arise all the time, and each one is tied to a concrete setting and is resolved by reasoning within its specific situation (Kirsh, 2009).

PS is taught in technology education and engineering (design process). It is taught all over the world mainly as a step-by-step process, the structural approach. This approach emphasizes the need for an ordered learning of the stages of the design process. Different models (differing mainly in terms of the number of stages into which the process is divided) were developed all over the world for teaching design as an organized and systematic process (e.g., in UK: DES, 1989; in the US: ITEA, 2000; in Australia, Kimbell, 1997; in Israel: Science and Technology Syllabus, 1996). As a result of the criticism of this approach, an alternative approach for teaching and learning PS was developed, the toolkit approach (functional approach), which emphasizes the teaching and study of PS toolkit (functions): issues identification and definition, exploration and investigation, decision-making, planning, making, and evaluation. At every stage of the process the problem solver may use more than one of the tools (functions) (e.g., investigation and evaluation), depending on the specific context and requirements of the particular stage (figure 1). Thus, function-contextual-traits are the basis for every activity implemented during the solution generation process (Mioduser & Dagan, 2007).

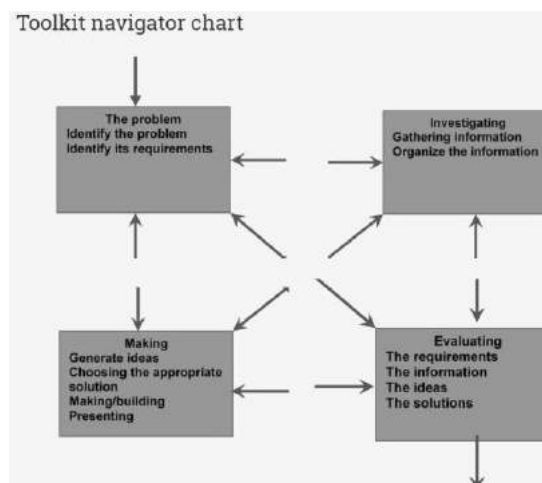


Figure 1. The problem-solving toolkit model

From the research of Mioduser & Dagan (2007), we might conclude that the toolkit (functional) approach towards design instruction was more effective than the traditional step-by-step (structural) approach in terms of supporting the construction of holistic, flexible, and effective mental models of the problem-solving process for technological solutions. This is the reason that we decided to use this approach while teaching PS as one of the ES included in the international online course.

#### 2.4. On-line learning in Higher Education

The OECD (2005) defined e-learning as “the use of information and communication technologies in diverse processes of education to support and enhance learning in institutions of higher education...”. Welsh et al. (2003) and Liu & Wang (2009) found that the features of e-learning process are centred on the internet; global sharing and learning resources; information broadcasts and knowledge flow by way of web courses, and lastly, flexibility of learning as a computer-generated environment for learning is created to overcome issues of distance and time. Twigg (2002) described the e-learning approach as centred on the learner as well as a system that is interactive, repetitious, self-paced, and customizable.

Gotschall (2000) argued that the concept of e-learning that based on distance learning, is thus a transmission of lectures to distant locations by way of video presentations. However, Liaw & Huang (2003) defined five characteristics for e-learning: a) using a multimedia environment; b) incorporating several kinds of information; c) supporting collaborative communication; d) supporting networks for accessing information and e) enabling implementation on various kinds of computer operating systems.

According to Tao et al. (2006), this environment for learning allows university students to receive individualized support and to have learning schedules that are more suitable for them, as well as separate from other learners. This facilitates a higher level of interaction and collaboration between instructors or faculty and peers than a traditional learning environment.

The Distance Education Enrolment Report 2017 (affirmed that distance learning continues to grow (3.9% every year), demonstrating that institutions remain committed to expanding programs that meet the needs of today’s students. Distance learning offers flexible, yet rigorous education opportunities that provide individuals with access to the in-demand skills needed to achieve their career goals (Online Learning Consortium, 2018).

The e-learning in HEIs is developed in two paths: a) Academic local on-line courses developed and delivered by the local faculty; and b) MOOC courses. This direction of development is increasing despite the high percentages of dropout from those courses.

For our IN2IT international online courses, we chose the local path and the MOODLE LMS platform, which enabled us to use innovative ICT-based pedagogy.

### 3. PS MODULE - DELIEVERY AND OUTCOMES

#### 3.1. The course structure

The ES course aims are: a) to provide students with the opportunity to develop soft skills; b) to boost students' employability skills and give them a competitive edge in the workplace and perhaps even in life; and c) to enable students to work in an international and virtual environment. They practice the ES on a given project while working on a shared goal with a virtual team. The course is built on five modules. Assessment of the students' achievements in the course, take place at the end of each module and at the end of the course.

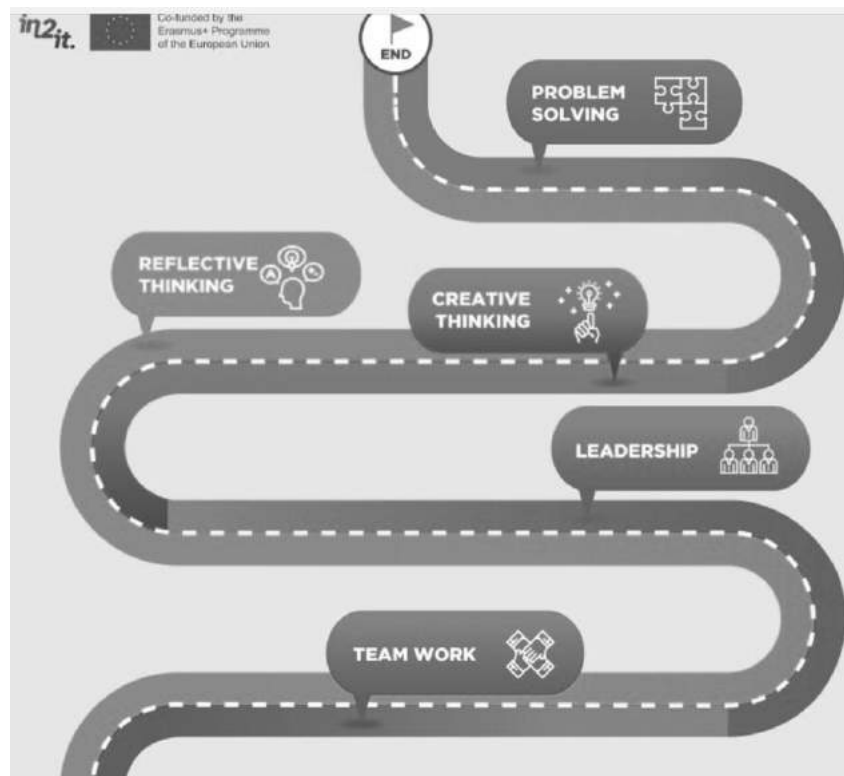


Figure 2. ES course roadmap

The ES chosen to be taught in this course are critical and reflective thinking, teamwork, personal leadership, creative thinking and PS. The roadmap describes the course path (figure2). The course begins with studying critical and reflective thinking, and then students use this skill at the end of each module. At the end of the course, the students have to use their reflective thinking in order to reflect on their learning process throughout course. The PS module is placed towards the end of the course, so that students can implement what they learned of the previous skills while solving a problem (e.g. while thinking about solutions they use what they learnt in creative thinking module).

#### 3.2. The Problem Solving (PS) Module

The PS module is based on the toolkit (functional) approach (Mioduser, 1998; Mioduser & Dagan, 2007), in which the students study what tools they can use in order to solve a problem. They learn that they can use the tools in any order, and they can use each one more than once (as shown in figure 1).

The structure of the PS Module: after a short technical introduction, there are two parts: an individual learning part and a collaborative implementation part.

In part (a), each student learns how to use the toolkit in the PS process through an interactive presentation, at the end of which he/she has to sketch their own path of using the toolkit and add it to a collaborative wall (figure 3).



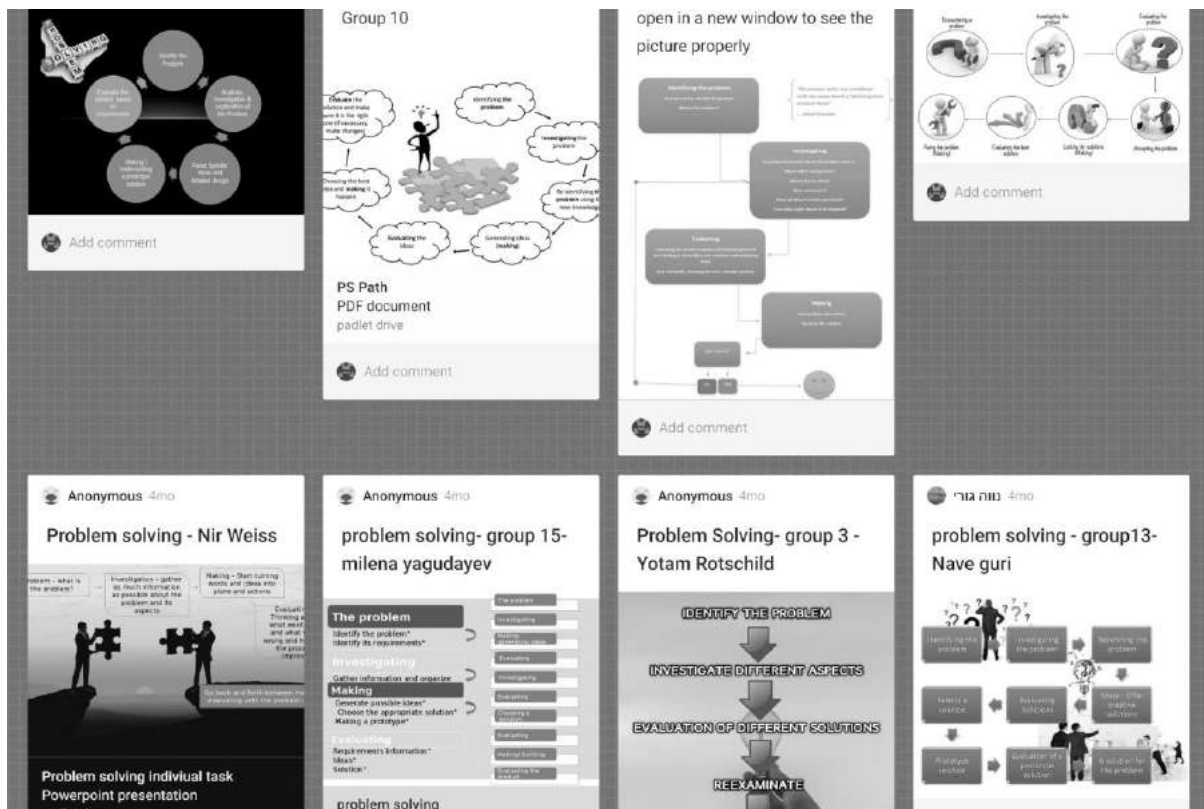


Figure 3. Part of the collaborative wall (PS paths)

In part (b) they work in international teams to follow a design brief (figure 4) using the toolkit to solve the problem.

## The Brief

Read the brief below, go to "the problem" and identify the problem and its requirements. Use the e-portfolio to document your process.

**The Brief**

**Manhattan transportation by numbers, NYC, USA**

During the day commuters from outside the city, nearly double Manhattan's population from 1.6 million to 3.9 million. These commuters divided to: 1.61 million commuting workers, 1.46 million local residences, 400,000 out of town visitors, 17,000 hospital patients and 70,000 commuting students.

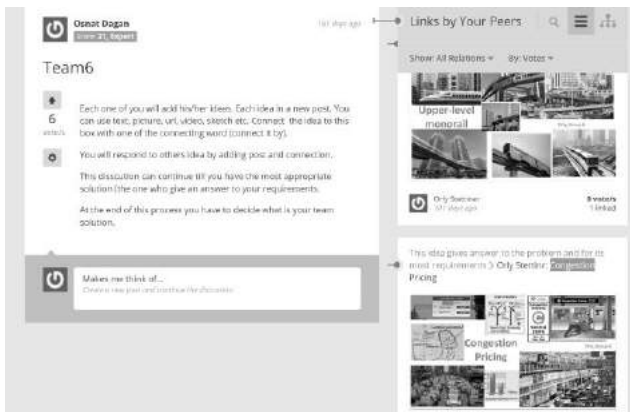
Around 48% of New Yorkers own cars. Yet, fewer than 30% of them use them on daily basis.

The people who arrive to Manhattan use the following transportation: around 16% of them use cars, around 17% use rail, around 14% use bus and around 50% use subway.

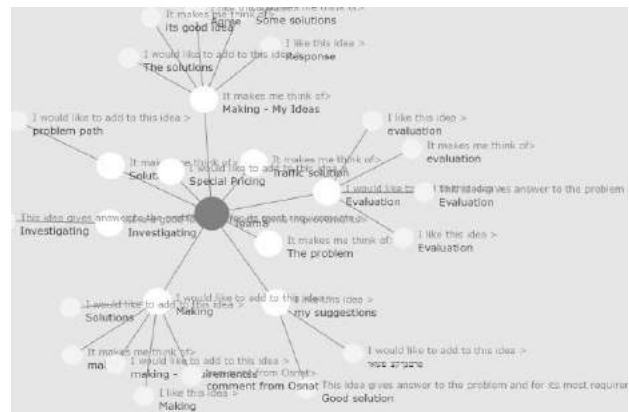
Even if most of them use the public transportation there are many who use their private cars and as such Manhattan roads are very crowded.

Figure 4. The PS Brief

They use a group forum to identify the problem and its requirements, they use the Ligilo software to raise ideas and decide on the most appropriate solution (Figure 5) and they used the gallery to present their solutions to other teams. Each student has to complete the personal portfolio for each tool that he/she used.



Ligilo group discussion



Ligilo group map

Figure 5. Ligilo

### 3.3 The PS module Delivery

The PS module lasted four weeks (with December holidays in the middle). About 110 students participated in the PS module. The students had to learn about PS, sketch their individual PS path (pre) (figure 3), work in international teams and solve the given problem (figure 4) while documenting their process in the personal portfolio. In their reflection questions, they had to once again, sketch their path for future PS processes (post). The comparison between the pre and the post paths will be processed in the near future.

Communication between the group members was not always easy, especially because of the holiday break. When the students had problems communicating via the tools that we offered to them (forums, Google, Webex, BBB, Skype) they used the WhatsApp. It was easy for them but it prevented us from following their processes.

### 3.4. The PS student's assessment

In each module of the course, the student could earn 20 points. The points for the PS were divided as follow: 10% for the personal path, 60% for the portfolio documenting the PS process (according to a rubric), 20% for the presentation of the solution (teamwork gallery) and 10% for the reflective questions. The criteria and the rubrics were introduced from the start of the module. We assessed both their work in teams and their individual processes.

## 4. CONCLUSIONS AND SUMMARY

E-learning and distance learning could be just the delivery of lectures (Golschall, 2000) and we know many such courses. In In2it courses we promise ourselves that we will use ICT in a manner that will enable us to focus on the learner, enhance active learning, and anywhere anytime collaboration (Welsh et al. 2003; Twigg, 2002; Liu and Wang, 2009). We did this in all four courses and in the Essential Skills course as well. The students told us in their reflective questions that the use of different ICT tools made the course more interactive, and interesting, and fit their abilities and learning styles.

From the students' reflections, we understand that: a) course content and tasks are essential, interesting and relevant; b) working in international and multicultural teams is important; c) peer tasks were good and relevant; d) students liked working/studying in an online environment and using new tools and e) ongoing feedback was an issue - students need feedback not just to see their grades but also to understand faculties' expectations.

From the students' reflections:

"The issue that relates to solving problems, I did not know that there are many possible paths to think about a problem and solve it. Because my engineering degree is primarily concerned with solving problems, this has contributed me and exposed me to new concepts that I did not know - especially in the evaluation of the solution" (student AD).

"I will certainly try to apply creative thinking in work and generally, problem solving in new situations, and leadership that is true leadership" (Student TG).

“In this process, I learned that even I believe that my solution is good it will be possible to develop it in a much better way by group thinking, which each one will present his idea and thus decide on the best way together. I think that mission helped me a little bit to a group player” (Student DW).

From the students outcomes we could understand that we accomplish our aims: a) the students experience using toolkit while solving a problem and know how to use it; b) they experience working in international teams and learnt from it and c) they used innovative technology and felt that it was useful for them.

We chose a complicate method for teaching PS (Mioduser & Dagan, 2007), which is even more complicated when it is in an online course. We believe that it is the right way to teach this subject. After taking into consideration some of the students’ feedbacks, we will improve the module and the course, for example: give fewer assignments, clarify the instructions and use different and friendlier tools for the portfolio.

In the forthcoming academic year, the improved course will be open for institutions that would like to participate.

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# Design Values, Preferences, Similarities, and Differences across Three Global Regions

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As technological advances connect countries from across the world, preparing students to contribute to an internationally connected society is paramount. An understanding of the various cultures, traditions, values, and educational practices is necessary for a more-fully integrated and preparatory curriculum. Specifically, we contend that in the area of open-ended design, identifying cultural, regional, and local preferences is a necessary undertaking to assist in preparing students for success in future endeavors. However, as open-ended design is an area that can be challenging to assess and implement, effectively identifying the design values and preferences unique to different locations are necessary. Identifying these preferences and values across locations may help illuminate best-practices to the teaching and learning for an increasingly culturally-sensitive open-ended design process. In this study, 706 American middle school students participated in an open-ended design project and submitted both prototypes and portfolios for their projects. Panels of teachers and researchers from the United States, England, Ireland, and Sweden were recruited to judge the student work through Adaptive Comparative Judgment (ACJ). Each panel was trained on the ACJ software (CompareAssess), introduced to the assignment and the assessment criteria, and provided a login to complete the ACJ. Through the final student project rankings, emerging from each of the judge panels in the ACJ process, highlighted large variations from region to region with only a few student projects appearing in the top ten rank for all regions. Comments provided by the judges, which explain the rationale behind their ACJ decisions, highlighted themes related to significant design values of each region. The identified values may help to enhance design and design-based learning across an internationally-connected society through an understanding of cultural similarities and differences.

*Key words: Adaptive Comparative Judgment, Design and Technology, Technology Education, Design Assessment, International Comparison, Intercultural Pedagogy*

## 1. INTRODUCTION

The emphasis on open-ended and design has spread through the science, technology, engineering and mathematics (STEM) educational movement. Many contend that a student's capability to perform on open-ended design tasks is necessary to prepare students for future employment opportunities as it emphasizes needed skills for today and workforce preparation (Bartholomew & Strimel, 2017; NAE & NRC, 2014; NRC, 2009; NRC, 2012; Strimel; 2014). However, succeeding locally in open-ended design is not enough; students need to be prepared to design in a globally-connected society (Edens, 2000) where cultural and regional differences can complicate collaborative endeavors. For example, something as simple as "unlucky numbers" can derail best-laid-plans and/or create new challenges for designers, architects, engineers, and educators (e.g., 13 is superstitious in the U.S.A. and Sweden, 4 is unlucky in China and Japan) (Idler, 2013; Shah, 2013).

Student success on an international level, particularly in open-ended design, may be, at least partially, dependent on student's understanding of styles, cultures, and preferences around the world. Research has shown that the majority of students are not prepared with this knowledge which is deemed necessary to succeed on a global scale (Gay, 2002).

While limited tools and resources exist to assist in this area, we propose that adaptive comparative judgment (ACJ) may be valuable for informing this area of research and practice. ACJ has recently been implemented in formative assessment and other educational learning settings (Bartholomew, Strimel, & Yoshikawa, 2017; Seery & Canty, 2017). Relatedly, researchers in Ireland have proposed using ACJ as a quasi-Delphi approach for identifying values and preferences of assessors (Seery, Delahunty, Sorby, & Sadowski, 2018). We investigated the potential for ACJ to be employed in this way to identify similarities and differences in design values across several different countries.

## **2. PROBLEM STATEMENT**

In order to understand, teach, and incorporate values of different people and cultures, teachers, administrators, and students need tools, approaches, and resources which can assist them in identifying these important principles (Lindsay & Simeon, 2016). Specifically, in the area of open-ended design, identifying cultural, regional, and local preferences can be challenging (Khan, Pitts, & Williams, 2016; Montgomery & McDowell, 2009). Therefore, research into new ways of identifying cultural design values and preferences needs to be undertaken to inform current educational practices. As these preferences and values are identified, they may be assimilated into best practices for teaching and learning in open-ended design scenarios toward influencing a more culturally sensitive (Getto & Sun, 2017) approach and output.

## **3. RESEARCH QUESTION**

1. What design values, if any, can be identified through adaptive comparative judgment performed by judges from different locations across the globe?

## **4. OPEN-ENDED DESIGN PROBLEMS**

We chose to study open-ended design problems in the context of K-12 education. Specifically, we utilized students from the USA working in Technology and Engineering Education (TEE) and teachers working in the areas of TEE (U.S.A.), Design and Technology (U.K./Ireland), and Teknik (Sweden). Each of these areas emphasizes open-ended design solving and problem-based learning pedagogies in a hands-on classroom environment (ITEEA 2000/2004/2007; Department of Education, 2013; Skolverket, 2011). While a complete illustration of the differences by country, their educational histories, and respective programs, is beyond the scope of this work, we provide a brief overview of the areas in each of the countries involved here.

In the U.S.A, this field of education is called Technology and Engineering Education (TEE). TEE's classes span topics such as computer-aided design, robotics, and control systems while fostering student abilities to design, make, and innovate (Starkweather, 2015). TEE classes are typically "elective" courses but do not have a consistent delivery in school systems across the country.

Similar to TEE, the UK has a program of study called Design and Technology (D&T) education. D&T is a subject which requires certain rigorous classes in which all students are required to utilize the design process (Design and Technology Association, 2014). Despite it being required, there remains a debate with policy makers of its importance and its position within education.

Sweden also has a mandatory curriculum for technology called "Teknik" or "Technology" in compulsory schools (Year 1 to Year 9). This subject has gone through several phases of change to introduce various programs and courses (Regeringskansliet, 2017). Despite it being mandatory, the content, assessment, and rigor fluctuates between schools (Hartell, 2015; Teknikföretagen & Cetis, 2013, Skolinspektionen, 2014).

## 5. ADAPTIVE COMPARATIVE JUDGMENT

The Technology Education Research Unit (TERU) in the U.K. (Kimbell, 2007) piloted an innovative approach to design assessment based on comparative judgment theories first set forth by Thurstone (1927). Thurstone suggested that comparative judgments in assessment is more valid than rubric assessments because of the instinctive nature of comparison. As artifacts go through a series of comparative judgments, a highly reliable rank order emerges (Kimbell 2012a, 2012b; Pollitt, 2004, 2012). A myriad of research related to ACJ, its use as a tool of assessment, its validity and reliability, and its feasibility for implementation has been conducted (Bartholomew & Yoshikawa, 2018).

In the ACJ process, a judge views pairs of work and identifies the “better” item according to predetermined criteria and/or personal expertise. As the judge continues through the process of comparatively judging pairs of work, a rank order is produced. This process also allows judges to add comments with the rationale for the judgments made. These comments allow the judges to provide justification and insight for why judgements were made (Bartholomew, 2017, Bartholomew et al., 2017; Hartell & Skogh, 2015).

The ACJ session also produces a calculated misfit statistic for each participating judge (Pollitt, 2004) which is a measure derived from Rasch-analysis, and can identify potentially controversial items and judges not acting consistently with their peers (e.g., one judge that is assessing differently from the group of judges). A more in-depth explanation of ACJ with the produced statistics can be found in work done by Pollitt (2004, 2012).

## 6. METHODS

This research took place across two continents. The student work was gathered from a school district located in the western U.S.A. This large school district services over 75,000 students and represents a mainly suburban middle-class population (16% free/reduced lunch which indicates that a student participates in a federally assisted meal program based on their household’s economic status). A total of six teachers were recruited for the study based on willingness to participate and possessing similar characteristics (teacher license level, similar years of teaching, similar classes taught, similar school facilities, and recommendation from the district TEE coordinator). Each teacher implemented the study in at least two sections of an introductory TEE course for 7th and 8th graders (12-14 years old). A total of 706 students were included in the study which took place over five class periods (two weeks of an alternating class schedule, 90-minute class periods). Students worked in groups of 2-3 to complete an open-ended design challenge around designing a new container/dispenser for distributing pills to patients in specified quantities and at prescribed times (see similar examples in Kimbell, 2007, 2012). Students designed the product for a specific user (an elderly individual who enjoys traveling internationally) and produced both a physical prototype and a design portfolio for submission.

Students groups moved through a brainstorming process where they were initially provided with materials chosen to stimulate ideation as well as pictures of pill containers and previous student creations. The students then proceeded to work with a “handling collection” consisting of materials to produce a final prototype. Students were also prompted by their teacher, at specified points throughout the duration of the project, to complete their portfolio.

Following the completion of the study all the student-group prototypes were collected and a digital picture was taken of each one, resulting in 176 images of student design prototypes and 175 pictures of student design portfolios (1 group did not turn in a portfolio). All these images were uploaded to the CompareAssess ACJ engine and were assigned to one of six different sessions (one session for each country for portfolios and one session for each country for prototypes).

### 6.1. Quantitative Data Collection.

Panel members were recruited in each of the participating locations for the ACJ assessment of student prototypes and portfolios: The United States of America, the United Kingdom (including those from Ireland), and Sweden. Panelists were selected based on their experience and expertise in technology and/or design education, and included practicing teachers, researchers, designers, and teacher-trainers (see Figure 1). While the majority of these individuals in the U.S.A. and Sweden had no prior experience with ACJ, the U.K. panel of

judges were almost all familiar with ACJ from previous projects (Williams & Kimbell, 2012). The previous collaborations, work, and experience with ACJ of the judges from the UK and Ireland provided the basis for combining these judges into one group. Further to this point, in previous projects, the judges from these countries demonstrated extremely high interrater reliability (Kimbell, 2012a).

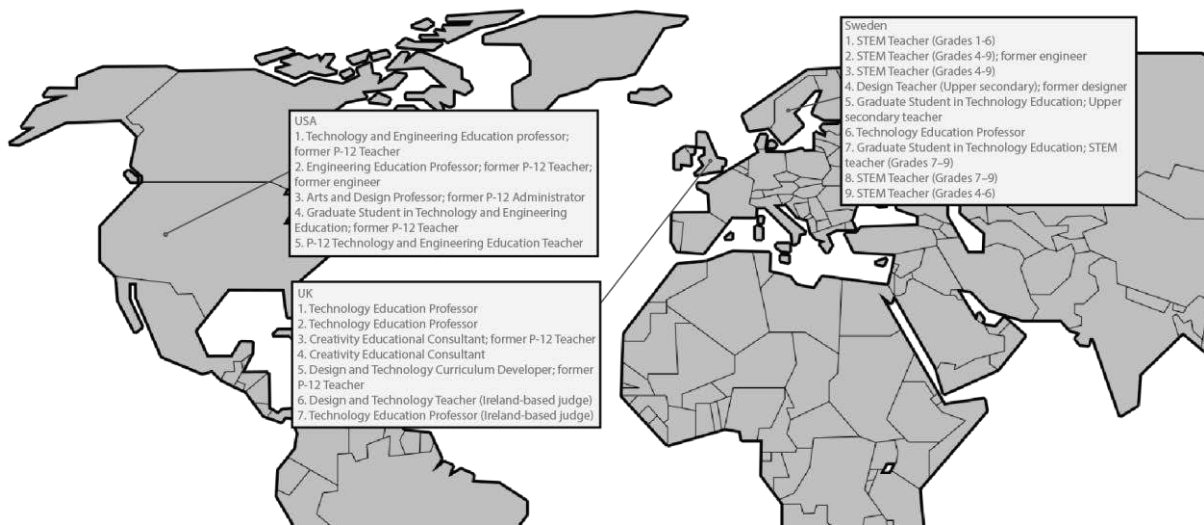


Figure 1. Backgrounds of panel members from each country.

Each group of judges was trained on the CompareAssess ACJ online judging platform, provided with individual logins, and introduced to the assignment and its criteria. Each judge was asked to make 20-30 comparative judgments of portfolios and student prototypes as an initial step in an effort to ensure all judges were confident and competent with the process. Following the initial judgment session, each judge was given the option to ask questions, resolve concerns, and discuss a collective direction in judgment. Subsequently each judge completed additional judgments until pre-determined reliability levels ( $r > .90$ ) were obtained for the resulting rank orders. A researcher monitored the rank order reliability level and upon reaching sufficient reliability levels, the judges were instructed that no additional judgments were needed.

Following the completion of each ACJ session the resulting rank orders, the time taken in judgments, and the judge comments from both the portfolios and prototypes, were recorded for conditioning and analysis. Prior to analysis all quantitative data was conditioned and tests for statistical assumptions were performed and satisfied.

## 6.2. Qualitative Data Collection.

In addition to the quantitative data recorded from CompareAssess the judge comments, from the ACJ sessions, were recorded. This was specifically done in an effort to identify the why behind judge decisions in ACJ and investigate the research question guiding this study.

Prior to coding, all judge comments from the Swedish judges were translated and reviewed by an independent reviewer to establish a common language across feedback. Additionally, England judge's vernacular used in comments were independently reviewed to ensure a correct cultural understanding of the meaning. The judge's comments were separated according to location and session (portfolio or prototype) and then coded using descriptive coding techniques (Miles, Huberman, & Saldaña, 2013) and grounded theory analysis (Charmaz & Belgrave, 2012). The first step in this process involved descriptively analyzing the comments to form possible codes that appropriately encapsulated the judge comments. This process produced the following codes: aesthetics, brainstorming, complete, criteria, design, design process, problem identification, reflection, consumer, developed, improvement, innovation, thought out, communication, realistic, size, complexity, follow through, potential, secure, usability, prototype, outcome, effort, neatness, construction, criteria, label, and organization. Additional codes, such as "error" (when the software did not properly load an artifact) and "equal" (when judges felt the two artifacts were equal in quality) were added after a second review of judge



comments (see Table 1). The codes were used to classify each comment from judges and the resulting counts for each code were recorded for later comparison across artifacts and between locations.

Table 1. Example of Judge Comment Coding.

Judge Comment	Code	Location
Easy to Pack	Size	Sweden
Stylish design, aesthetically thorough	Aesthetics, Design	Sweden
Wins because it is a more developed solution	Developed	U.K./Ireland
Looks easier to use	Usability	U.S.A.

## 7. FINDINGS

The findings from this research include the rank orders and parameter values for both prototypes and portfolios and the judge comments from their comparisons. The findings, from both the quantitative and qualitative analysis, are presented here in conjunction with each corresponding research question.

**RQ1:** What design values, if any, can be identified through adaptive comparative judgment performed by judges from three locations across the globe?

After coding the judge feedback, themes emerged which may illustrate judges' values and preferences in both the prototypes and portfolios. Importantly, these themes emerged from judges using an identical assignment description, assessment tool, and evaluation criteria. The themes for the portfolio assessments will be presented first (by location), followed by the themes for the prototypes.

### 7.1. U.K. Prototype Themes

The U.K. judges seemed to value uniqueness in ideas when evaluating the prototype images (see Table 2). Although not universal, novelty was often valued over functionality. Additionally, these judges tended to value if the prototype was developed or looked more complete.

Table 2. Example of U.K. Judge Prototype Comment Coding

Comment	Code
chose B as the pots were arranged differently!	innovation
Is it a better pill holder - no idea???	
Marginal - A more complete concept	developed
wins because it is a more developed solution	developed
no idea what [is] going on but different	innovation
potentially more user friendly	usability

### 7.2. Sweden Prototype Themes

The comments from the Swedish judges suggested a value on size, usability, and design (see Table 3). Judges often commented on whether or not a prototype could fit into a purse or carrying case (one of the constraints for the assignment) and used this as a measure in determining which prototype to select.

Table 3. Example of Swedish Judge Prototype Comment Coding

Swedish Comment	Translation	Code
a verkar enkel och funktionell.	a seems simple and functional	usability
A is smaler	A is smaller	size
B har en spännande formgivning	B has an exciting design	design
A är en enkel idé och har en kompakt form. Bra i väskan.	A is a simple idea and has a compact design/shape. Good to have in purse/bag	design; size

### 7.3. U.S.A. Prototype Themes

The judge comments from the U.S.A. indicated a value on usability and how easy the prototype was to both use and figure out how to use (see Table 4). Another common theme in these comments was the size (e.g., how compact the prototype seemed). The judge comments also reflected an importance in design quality.

Table 4. Example of U.S.A. Judge Prototype Comment Coding

Comment	Code
Looks easier to use	usability
More compact. user-friendly	size; usability
love the idea looks like it can hold all the days etc.	design

In addition to submitting prototypes, the students also submitted portfolios that were created throughout the design process. The same process was utilized to identify themes for all three regions for portfolios submitted by students.

### 7.4. U.K. Portfolio Themes

The themes that emerged from the U.K. judge comments were focused around the development of the prototype (see Table 5). The comments focused on how well students followed through with plans that were initially proposed in student portfolios. They also showed interest in whether or not the students showed uniqueness and creativity in the prototype. These judges appeared more likely to choose a design if it was different – regardless of whether it aligned well with the assignment criteria.

Table 5. Example of U.K./Ireland Judge Portfolio Comment Coding

Comment	Code
both obvious solutions and very thin. tossed a coin	equal
B - more developed	developed
B has more innovation and exploration but A is more resolved by the end.	innovation; developed
Flower version a bit more interesting ...	innovation

### 7.5. Sweden Portfolio Themes

The comments from the Swedish judges revolved more around the actual prototype produced and how well it was communicated in the portfolio (see Table 6). Communication was the most common theme for the Swedish judges with a majority of comments centered on whether or not a design portfolio fully communicated a particular idea; often this was related to comments around the completeness of the design portfolio. Additionally, many of their comments focused on the prototype that came out of the portfolio instead of the portfolio itself.

Table 6. Example of Swedish Judge Portfolio Comment Coding

Swedish Comment	Translation	Code
a verkar enkel och funktionell.	a seems simple and functional	usability
A is smaler	A is smaller	size
B har en spännande formgivning	B has an exciting design	design
A är en enkel idé och har en kompakt form. Bra i väskan.	A is a simple idea and has a compact design/shape. Good to have in purse/bag	design; size

### 7.6. U.S.A. Portfolio Themes

The U.S.A. judges most commonly reported that their judgments on the portfolios were based on whether or not the portfolio met the assignment criteria and how well the students demonstrated progress through the design process (see Table 7). These comments specifically mentioned brainstorming, reflection on the design produced, and multiple iterations.

Table 7. Example of U.S.A. Judge Portfolio Comment Coding

Comment	Code
B has a more polished and perhaps more functional product but A has a better overall portfolio	complete
B provides evidence of understanding more of the criteria throughout the portfolio	criteria
The other one did not identify criteria or constraints	criteria
More complete reflections at the mid-point of the design process	reflection
Better job answering prompts and providing information	complete

The coding of judges’ comments resulted in a variety of codes for each location. Every judge comment was coded and the total quantity of codes was calculated by location (see Table 8) in an effort to identify the overall values, which guided judges’ decisions in each location.

Table 8. Top codes produced through thematic analysis by location

	Products		Portfolios	
U.K./Ireland	Innovation	21.60%	Developed	26.65%
	Developed	16.20%	Innovation	22.85%
	Usability	14.46%	Follow Through	10.02%
	Size	13.07%	Equal (both items were the same quality)	5.21%
	Equal (both items were the same quality)	7.67%	Thought Out	5.21%
Sweden	Usability	17.96%	Communication	20.50%
	Size	17.77%	Design Process	13.21%
	Design	16.26%	Complete	12.07%
	Clear Labeling	10.59%	Better	11.62%
	Construction	8.88%	Outcome	10.71%
U.S.A.	Usability	25.30%	Criteria	29.18%
	Size	18.27%	Complete	25.90%
	Design	16.87%	Reflection	13.77%
	Secure	13.86%	Brainstorming	10.16%
	Aesthetics	6.43%	Design Process	6.23%

## 8. CONCLUSION AND RECOMMENDATIONS

This study sought to leverage ACJ—a tool originally designed for assessment—in a modified-Delphi approach to identify similarities and differences in design values from various locations. We posit that understanding these similarities and differences in design values and preferences across different locations can assist in preparing students for future employment and engagement in a globally connected society. The findings suggest that ACJ can be used in a modified-Delphi fashion that presents potential for future research efforts. Further, the data collection, analysis, and accompanying findings resulted in several themes, which may point toward future areas of research while also providing an interesting foundation for discussion and immediate implementation.

### 8.1. Prototypes: Form and Function

Interestingly, the argument for favoring form or function appeared to be one that happens between locations rather than within locations. In this research the judges in each location showing high-levels of agreement in their paradigm towards the prototype assessment while differing from other locations’ judges. The judges in the U.K. consistently demonstrated in their comments that they valued form and judges in the U.S.A. and Sweden appeared more concerned with functionality.

## 8.2. *Portfolios: Criteria, Communicating Results, and Demonstrating a Journey*

Judges from the U.K. emphasized how developed a portfolio was or how well it demonstrated progress in design. Judges from Sweden emphasized communication; these judges wanted to know how well the portfolio could communicate the process, results, and conclusions to the judges. Finally, judges from the U.S.A. emphasized how well the students identified and followed the criteria and constraints and overall how complete their portfolio was (i.e., did the students fill in each box). While a full discussion of these implications and the associated educational paradigms of each country is beyond the scope of this work, it is interesting to note the contrasting themes and conjecture on the long-term outcomes of students immersed in each set of values.

## 8.3. *“Good Design” – A Regional Phenomenon?*

Relatedly, a leading researcher in cultural studies (Hofstede, 2003; 2011) has identified six dimensions of culture (power distance, individualism, masculinity, uncertainty avoidance, long-term orientation, and indulgence) and has assigned a score to each country based on their own culture. This was done using a variety of techniques, criteria, and approaches (Hofstede, 2011) and a look at the identified countries (U.K, U.S.A., Sweden) revealed relative comparability in almost all areas with the exception of “masculinity” – a measurement related to the competitive mindset of individuals (Hofstede, 2011). The U.S.A and the U.K. were very similar in Hofstede’s values (scores of 62, 66) while Sweden had a significantly different masculinity score (score of 5). This suggests a potentially significant difference in cultural values around competition (Hofstede, 2003, 2011)—an interesting finding that may be connected with the differences in preferences of the Swedish judges. Further research comparing Hofstede’s identified cultural dimensions with emerging design cultures and values from ACJ assessment sessions is an area of particular interest to these researchers.

Seeking to identify the design values of countries through ACJ was an intriguing and fruitful project. As expected, this research raises more questions than answers but we are encouraged by the approach, the initial findings, and our conclusions. It is our hope that future work into “good design” and design education will build and expand on this work.

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# Implementing Digital Technology in the New Zealand Curriculum

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Understanding of and competency in developing digital technologies is becoming an increasingly debated topic around the world. Perceived as being closely linked to economic development in a world that is beginning to rely less and less on natural resources, and more and more on intellectual resources governments are keen to make progress in this area. Key areas of debate include where and when key components of digital literacy such as: computation thinking, computer science, programming, and coding should be learned. This paper reviews literature that argues for a place for digital technologies in the curriculum. It then outlines the decision making process of New Zealand as it moves to implement digital technologies in the New Zealand Curriculum. It argues for the inclusion of digital technologies in the curriculum and more specifically within the technology curriculum. Next it gives a detailed account of the processes undertaken by the New Zealand Ministry of Education to implement digital technology up to the time of writing at this time that final revised curriculum is due. Finally, it offers a cautionary warning about two potential risks as New Zealand enters the implementation phase of its new digital technologies curriculum.

*Key Words: Digital technologies, Implementation, Curriculum, Technology education.*

## 1. INTRODUCTION

As we move, further and further into the digital age there is recognition both internationally and in New Zealand about the need for digital technologies within the curriculum. In July 2016 the Minister of Education announced that digital technologies needed to have greater focus and be more explicit in the New Zealand curriculum (Ministry of Education, 2017a) and would be introduced into The New Zealand Curriculum (NZC), coming under the umbrella of technology education (Education Gazette Editors, 2016; Stuff, 2016). The decision to situate digital technologies within the technology curriculum was somewhat controversial and came after an 18-month period of consultation with a range of interested sectors. Welcomed by the technology education sector, the decision was not a popular one for the IT sector, who believed that digital technologies would be “pigeon-holed” with woodwork and sewing” (Curzon, 2016) and therefore lobbied strongly for a separate digital technologies learning area within the curriculum. This paper presents a rationale for situating digital technologies within technology and outlines the process undertaken by the New Zealand’s Ministry of Education (MOE) decision to situate digital technologies within Technology.

## 2. IMPLEMENTING DIGITAL TECHNOLOGIES IN SCHOOL CURRICULA

Over the last ten years digital technologies and the role they play in education has been a matter for global discussion. There is general agreement that digital technology belongs in the school curriculum in the 21st Century (Bell, Andreae, & Bobins, 2014; Falkner, Vivian, & Falkner, 2014; Gander et al., 2013; The Royal Society, 2012). Two aspects of digital technologies are of particular interest; the teaching of computer science (informatics, computational thinking) and information systems (Falkner et al., 2014). Since computers made their way into the classroom there has been a change in learning focus from learning to use computers and more recently other digital technologies to that of learning with them. For example Bell, Andreae & Robins (2014) state that in New Zealand, after some initial teaching of computer programming in senior secondary mathematics classes in the early 1970s teaching became dominated by teaching students how to use computers. This occurred in the international arena as well (Gander et al., 2013; The Royal Society, 2012) despite in the early 1980s Papert (1980) suggesting that computers would impact on the way people think and learn and that young children should be not only taught to use computers but to programme computers. “One might say that

the computer is being used to program the child. In my vision the child programs the computer” (p. 5). Somewhat ahead of his time, Papert was right. Digital technologies is more than students learning to use their devices rather the current focus is having students developing digital technologies in accurate and ethically acceptable ways, with humanity and people at its core, (Bell & Duncan, 2015; Bell & Roberts, 2016; Starkey, 2016). In their statement about strengthening the position of digital technologies in the curriculum New Zealand’s Ministry of Education said “Once this new curriculum is introduced, our kids will not just be using devices like computers and smart phones. The changed curriculum will mean that schools will be teaching our young people the computer science principles underpinning all digital technologies. Students will find out about how computers work – understanding what makes ‘algorithms’ and ‘binary code’ (2017c).

There is currently a strong call for computational thinking, computer science, information systems education to be included in curricula from the beginning of primary schooling, (Armoni, 2016; Falkner et al., 2014; Gander et al., 2013; Webb et al., 2017). A growing body of knowledge indicates that aspects of computational thinking and computer programming, rather like that of learning languages, is best begun at an early age, at least before the age of 12 but more ideally around eight years of age (Bell & Duncan, 2015; Duncan, Bell, & Tanimoto, 2014; Gander et al., 2013; Webb et al., 2017). Bell and Duncan suggest that in addition to general benefits of working collaboratively there are a number of specific reasons for young students being exposed to and taught digital technologies. Students before the age of 12 are forming views of their competence in subjects; students have a more natural ability to learning foreign languages before puberty; students can be empowered to change the world rather than be passive participants; and it prepares students for a future in computing.

### **3. RATIONALE FOR IMPLEMENTING DIGITAL TECHNOLOGIES WITHIN THE CURRICULUM**

Learning in the 21st Century presents teachers with a challenge of equipping students with skills and knowledge necessary to survive in the digital age and beyond. Many new ideas challenge current educational assumptions therefore schools need to change significantly to meet new and emerging needs of today’s students (Gilbert, 2005). Many education programmes continue to be out of step with students’ current lives and seem irrelevant to their future lives (Bellanca & Brandt, 2010). Skills supporting innovation, creativity, critical thinking, and problem solving are needed to fulfil the expectations of the new economy (Compton, 2010). Wagner (2008) advocates seven survival skills for the 21st Century:

- Critical thinking and problem solving
- Collaboration across networks and learning by influence
- Agility and adaptability
- Initiative and entrepreneurialism
- Effective oral and written communication
- Accessing and analysing information
- Curiosity and imagination

Bellanca & Brandt (2010) suggest a number of core 21st century themes, which in essence are the same as those above and also include the need for media and information and communication literacies. In considering the requirements for 21st Century learning, Claxton (2007) too identifies the need for a greater and different student learning capacity, therefore an epistemic culture change is needed in schools to replace stand-alone courses in thinking skills or ‘tricks of the trade’ type learning.

The Ministry of Education (2017a, p. 5) states that children and young people often already arrive at school knowing how to use digital technologies – but learners also need to be able to understand and create digital technologies to succeed in further education and the world of work. In the wider economy, businesses struggle to find people with the right skills to drive digital innovation and economic growth. They also state that this learning needs to start in the classroom.

## **4. RATIONALE FOR IMPLEMENTING DIGITAL TECHNOLOGIES WITHIN TECHNOLOGY IN NEW ZEALAND**

Technology is intervention by design: the use of practical and intellectual resources to develop products and systems (technological outcomes) that expand human possibilities by addressing needs and realising opportunities. Adaptation and innovation are at the heart of technological practice. Quality outcomes result from thinking and practices that are informed, critical, and creative.

Technology makes enterprising use of its own particular knowledge and skills, together with those of other disciplines. Graphics and other forms of visual representation offer important tools for exploration and communication.

Technology is never static. It is influenced by and in turn impacts on the cultural, ethical, environmental, political, and economic conditions of the day (Ministry of Education, 2007, p. 32).

To understand fully the place of digital technologies within technology we first need to have a deep and insightful understanding of the underlying philosophy of technology education (de Vries, 2005) and how it should be implemented. Technology, although a relative late comer to the academic domain is well established (de Vries, 2017). Technology education is about understanding the nature and complexity of technological artefacts, knowledge and processes to design and develop technological outcomes (products and systems). Students need to understand the role and implications of a large range of factors such as: scientific, technological, market, political, juridical and ethical to inform their practice (de Vries, 2005). Technology is not about making outcomes with the purpose of learning a specific set of skills, as was common in former technical programmes. It is about students becoming skilful and knowledgeable enough to enable the development of successful, socially situated technological outcomes. Technology education is also about students learning to understand how technologies and people interact and influence each other, as well as designing and developing outcomes that are fit for purpose. The following description of the structure of technology in NZC further explain these ideas.

As with all learning areas in NZC, a number of strands make up technology. Learning is divided into eight achievement objectives across eight achievement levels from L1-L8 for students aged 5-18 years of age. Situated within three strands, the technology achievement objectives lead to technological literacy for students with an aim to not only survive but also flourish in their current and future technological worlds. This includes being critical and informed developers of technological outcomes as well as critical consumers of technology.

### ***4.1 Nature of Technology***

The Nature of Technology strand assists students' development of the understanding of technology as a discipline and of how it differs from others. It also includes learning to critique the impact of technologies on people and societies and the environment. This includes exploration of specific technological developments and outcomes including how different peoples value them in and across different times. Students come to appreciate the socially embedded nature of technology and become increasingly able to engage with current and historical issues and to explore future scenarios.

### ***4.2 Technological Practice***

This strand is the practical strand of the curriculum in which students design, develop and evaluate technological products or systems. Students study the practice of technologists and undertake their own technological practice in a way that mirrors that of existing practice as closely as possible. Students develop a range of technological outcomes (products or systems), including concepts, plans, briefs, technological models, prototypes and fully realised products or systems. In order to increase the likelihood of developing successful outcomes students investigate issues and existing outcomes within the context of each project. They also interact with their clients and other stakeholders and then use their new findings and understandings, together with design principles, to inform their own practice. They also learn to consider ethics, legal requirements, protocols, codes of practice, and the needs of and potential impacts on their major stakeholder (or client), other stakeholders and the environment.



Essentially technology education is about designing and developing technological outcomes, understanding how to undertake a rigorous design and development process and to situate technology within the human and physical worlds through the identification and understanding of impacts and influences technology has on planet Earth and its people. Technology offers an holistic approach to education within which students best work immersed in authentic learning contexts (Turnbull, 2002) to solve technological problems.

Given the definition of technology and the very clear directive from the Ministry of Education in New Zealand that Digital technologies is about designing and developing digital outcomes the question to be asked is why would it not be situated within technology?

There is a danger that implementation of digital technologies, especially computation thinking if taught in isolation, become a series of skills and facts that students are expected to learn without fully understanding their role and purpose. While we acknowledge that, many skills and concepts need teaching for students to develop confidence and competence in computer science and programming during their school years. In addition, these concepts are most successfully learned when introduced to students under the age of eight (Bell, T. personal communication July 2016), digital technology learning must emerge from within a social context and must not occur in isolation from people and their values and beliefs. It is imperative that students learn digital technologies within an authentic context and that they are given opportunities to explore, to collaborate, be creative and be resilient, within purposeful learning. Technological outcomes should be constructed within a particular culture, taking into consideration the social and cultural needs of the society in which they are developed, and those of their developers (Bellanca & Brandt, 2010; Fleer & Jane, 1999). The need for skills and knowledge therefore becomes authenticated because students understand the purpose of their learning (Turnbull, 2002). This in turn leads to better engagement and motivation by students (Fox-Turnbull & Snape, 2016; Snape & Fox-Turnbull, 2011). By teaching the designing and developing of digital technologies and computational thinking through all three strands of the technology curriculum and using authentic context for learning teachers are assured that their students will be given the best opportunities for success in technology.

The Ministry of Education in New Zealand has identified that the demand for digitally skilled people is far in excess of those who are available to work in the digital related field. New Zealand's technology industry state that increasing workforce capabilities in this area will better place New Zealand in the global market place. The Ministry of Education has thus recognised the need to change the education curriculum to enable students to be better prepared for and to flourish in a digital world, within which technologies are forever changing and evolving (Ministry of Education, 2017c).

## **5. DIGITAL TECHNOLOGIES SITUATED WITH TECHNOLOGY EDUCATION IN THE NEW ZEALAND CURRICULUM**

The process the Ministry of Education (MOE) used to come to this decision and the pathway undertaken in the implementation process, presents a rationale for and supports the Ministry's decision to situate digital technology within technology.

### ***5.1 Technological Knowledge***

Through the technological knowledge strand, students develop knowledge particular to technological enterprises and environments and understandings of how and why things work. This strand includes understanding the theory of technological modelling, the role and impact of materials on the design of products and understanding how technological systems are designed and tested. Theoretically based, in this strand students learn to understand why they are making specific design decisions and undertaking specific tasks within their own practice. For example students learn what modelling is and why modelling is critical when developing technological outcomes, rather than undertaking the actual modelling.

### ***5.2 Technological Areas***

The above three strands will not change across much of technology with the implementation of digital technologies, as they are relevant and applicable; however the technological areas will change significantly. The NZC technological areas (Ministry of Education, 2007) ensure students gain a range of experiences and contexts in their studies. These included biotechnology, control technology, food technology, information and

communication technology, and structural technology. As can be seen from above curriculum definition graphics and other forms of visual representation are necessary tools for exploring and communicating design ideas and therefore sat across all strands. These strands have been reorganised and named to ensure digital technologies has a stronger presence in the curriculum. The proposed new five technological areas are:

- Computational thinking for digital technologies
- Designing and developing digital outcomes
- Designing and developing materials outcomes
- Designing and developing processed outcomes
- Design and visual communication

There is a close relationship between the old and new areas of technology; however, the new ones have explicit mention of digital technologies and DVC. Table 1 suggests links between the 2007 and new 2018 strands of technology.

*Table 1. Links between the 2007 and draft 2017 strands of technology.*

2017 Proposed Technological Areas	2007 Technological Areas
Computational thinking for Digital Technologies	New
Designing and developing digital outcomes	Aspects of control technology, electronics Aspects of information and communication technologies
Designing and developing materials outcomes	Structural technology including: resistant materials (wood, plastic, metal, resin) garment and fashion design Aspects of control technology such as hydraulics, pneumatics, e-textiles
Designing and developing processed outcomes	Food technology Biotechnology Textile design (new materials and fabrics)
Design and visual communication	Previously an aspect of all design and situated across all technological areas with DVC specialism at senior secondary school.

The draft digital technologies document (Ministry of Education, 2017a) suggested that the existing strands be only applicable to the latter three strands and that new progressions were being written for the new digital strands, however there is an argument that would support the second technological area, 'Designing and developing digital outcomes', also using the existing strands.

## **6. THE PROCESS UNDERTAKEN BY NEW ZEALAND TO DETERMINE THE PLACE OF DIGITAL TECHNOLOGIES**

New Zealand was an early adopter of computer science in secondary schools (Bell & Roberts, 2016). In the early 2000s national assessment for senior secondary students was available through unit standards computer science. These were not a popular choice with 'academic' students as they were assessed at 'achieved' or 'not achieved', therefore not enabling students to gain 'merit' or 'excellence' grades (Bell et al., 2014). Digital technologies became a mainstream subject in National Certificate in Educational Achievement (NCEA) qualification beginning with Year 11 in 2011 at Level 1 achievement standards (AS), rolling out to Year 13 in 2013 at Level 3. This change was a part of the NZC/NCEA alignment project which aimed to align the 2007 curriculum (Ministry of Education, 2007) with NCEA assessment standards. Prior to this focus was on learning to use computers rather than to be developers. This change meant considerable up-skilling for teachers to enable the coverage of a range of computer science related topics including programming, algorithms, computer human interaction, encryption, artificial intelligence, formal languages, computer graphics among others. An emphasis on breadth rather than depth aimed to assist students with informed career choices. (Bell et

al., 2014). Prior to this there was some initial teaching of computer programming as a part of the mathematics curriculum from 1974 to 1985, however as school computers became more mainstream teaching and learning focus shifted to teaching students how to learn to use computers, which has continued to the present day.

When technology education was introduced into the New Zealand curriculum in 1995 ‘Information and Communication technologies’ was one of the seven technological areas, Electronics and Control technologies was another (Ministry of Education, 1995). The year 2007 saw the release of the revised The New Zealand Curriculum, within which the technological areas Information and Communication Technology and Control Technology were situated (Ministry of Education, 2007). There were concerns that many schools did not engage with topics situated within these technological areas, despite some attempts to guide teachers into a deeper and richer approach to computing education (Bell et al., 2014).

Industry and tertiary concerns about the lack of a potential skilled IT workforce were raised in a report released by the New Zealand Computer Society (now known as The Institute of IT Professionals or IITP) in 2008. The main concern was that the generic achievement standards of technology used to assess senior secondary technology did not obviously relate to digital technology (Grimsey & Phillipps, 2008, cited in Bell et al., 2014). This led to the society calling for a separation of Computer Science from the technology education curriculum and for it to have its own learning area within the New Zealand curriculum (Bell et al., 2014). It must be noted that many people involved in technology education disagreed with the view of the report and felt that it was based on a narrow and out-dated view of technology education and what should have been occurring in schools at the time.

In 2015 the Education Minister called together a panel of experts from a range of sectors to debate the place of digital technologies in the curriculum (Starkey, 2016). A series of three meetings were held throughout the year. At the first meeting, with this author in attendance, the Associate Deputy Secretary indicated to the assembled group that the ministry was using a new consultation approach. Instead of consulting with each sector individually as they had in previous consultation processes, all interested parties were invited to this series of meetings to discuss and debate the issues and develop a recommendation for the Minister of Education to consider. The sectors and organisations represented at the meetings included:

- initial and in-service teacher education providers
- primary schools, secondary schools, early childhood centres (including Māori medium)
- computer science researchers
- three teacher subject associations (Technology Education New Zealand, TENZ; New Zealand Graphics and Technology Teachers Association, NZGTAA; New Zealand Association of Computer and Digital and Information Technology Teachers, NZACDITT)
- information technologies industries
- the New Zealand Qualifications Authority (NZQA)
- the Education Review Office (ERO)
- the primary and secondary teacher unions (NZEI and PPTA)
- the Eureka trust
- the Royal Society
- the Schools’ Trustees Association (NZSTA)
- Kia Ata Mai Educational Trust
- Education Council
- Kura Kia Kohe

As Starkey (2016) states a wide range of views were held and vigorously debated in the first of the three meetings and it became obvious that a research-informed framework would be required to further discussion. Some participants presented views from their organisations, these included Professor Tim Bell- University of Canterbury computer science department, Julie McMahan-NZACDITT, Wendy Fox-Turnbull-TENZ and Paul Matthews-IITP. The Institute for IT Professionals advocated strongly for a separate curriculum area (IITP, 2015). TENZ strongly advocated for digital technology remaining within technology. NZACDITT offered a balanced argument for within technology, with a number of cautions noted and Professor Bell indicated that

staying within the technology curriculum was possible, not necessarily, the most desirable but that digital technologies needed a much stronger presence than was currently in the technology curriculum.

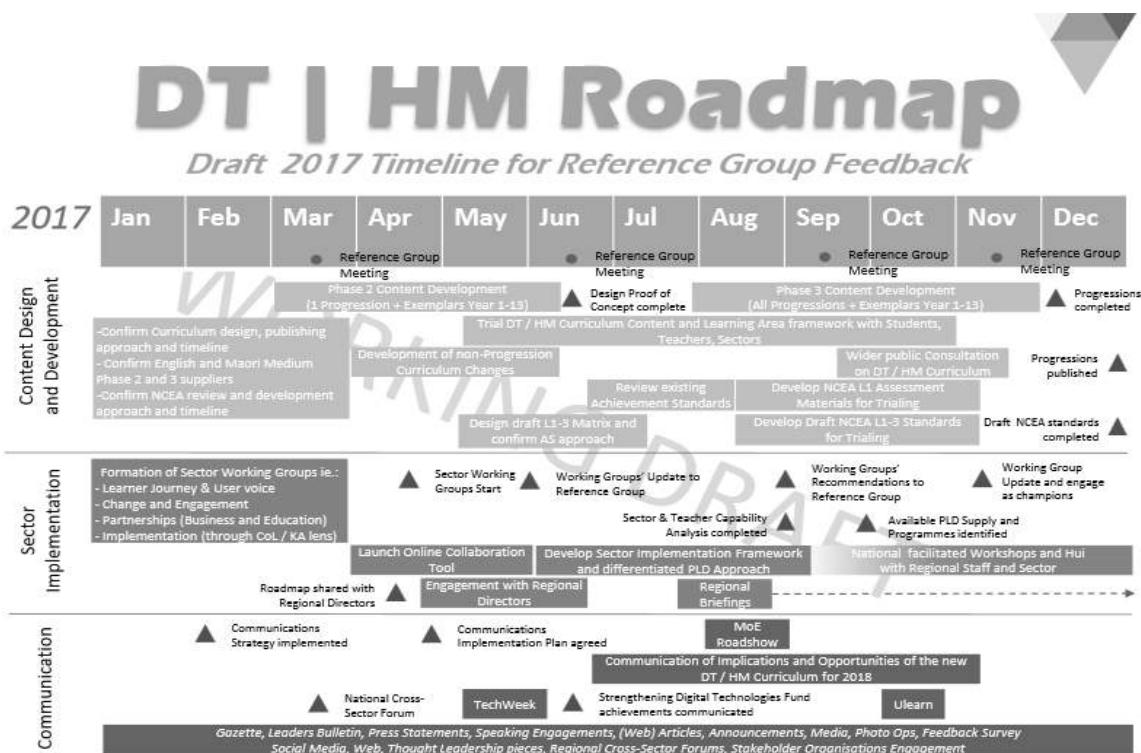
Ultimately, the recommendation that went forward to the Minister of Education in December 2015 suggested that digital technologies remain situated within the technology learning area, but that it receive a far greater presence than it currently had. In July 12 2016, the Minister of Education announced a strengthening of digital technologies within NZC situated under the umbrella of technology education coming into effect in 2018. It was planned that professional learning development (PLD) begin Term 1 2018 and by Term 1 2020 it is expected that all schools will be teaching the Digital Technologies/ Hangarau Matihiko within the technology education curriculum (Ministry of Education, 2017b).

## 7. DEVELOPING DIGITAL TECHNOLOGIES CURRICULUM AND IMPLEMENTATION INTO NZC

In the beginning of 2017 the ministry developed a planned implementation process (Figure 1) to ensure a multi-pronged approach and set up five working groups to identify the nature and format of the new look technology curriculum and as an overall part of the implementation process. The five working groups were:

- Enablement & Change
- Implementation & Support
- Partnerships,
- The Learner Journey & User Voice
- National Certificate of Educational Achievement (NCEA).

Undertaking a similar and parallel process Māori developed Hangarau Matihiko. This work culminated with the launch of the Digital Technologies/Hangarau Matihiko: Draft for Consultation curriculum document (Ministry of Education, 2017a) in June. New content included two new technological areas of ‘computational thinking for digital technologies’ and ‘designing and developing digital outcomes’ as outlined above but also containing unique Māori content. At the launch the Minister of Education with the Prime Minister also announced that the government would spend \$40 million on raising teachers' skills to deliver the new curriculum, involving all pupils from Years 1-10 taking part in digital technologies education.



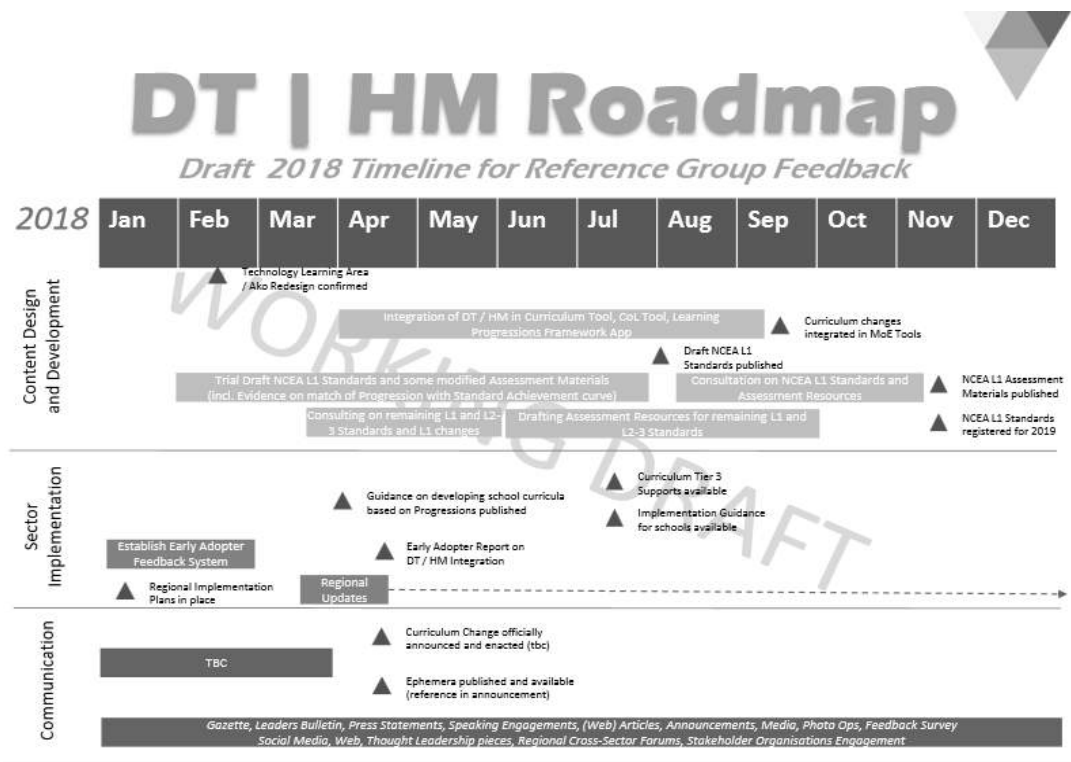


Figure 1. Planning for the Implementation of Technology

The Ministry of Education established a curriculum advisory group (CAG) as an independent panel of experts commissioned to advise the Ministry on the draft curriculum content including the content from the working groups and provide recommendations on feedback received during consultation. This work was collated in the Curriculum Advisory Group Report (Curriculum advisory group, 2017). Significant projects undertaken by the working parties included a drafting of the proposed new structure of technology/ hangarau, the first and final drafts as seen in Figures 2 and 3. The rewritten essence statement, which provides an overview of the curriculum area, reflecting the inclusion of digital technologies (Ministry of Education, 2017a), learning processions for Year 1-10 students in the new content and new and modified NCEA achievement standards.

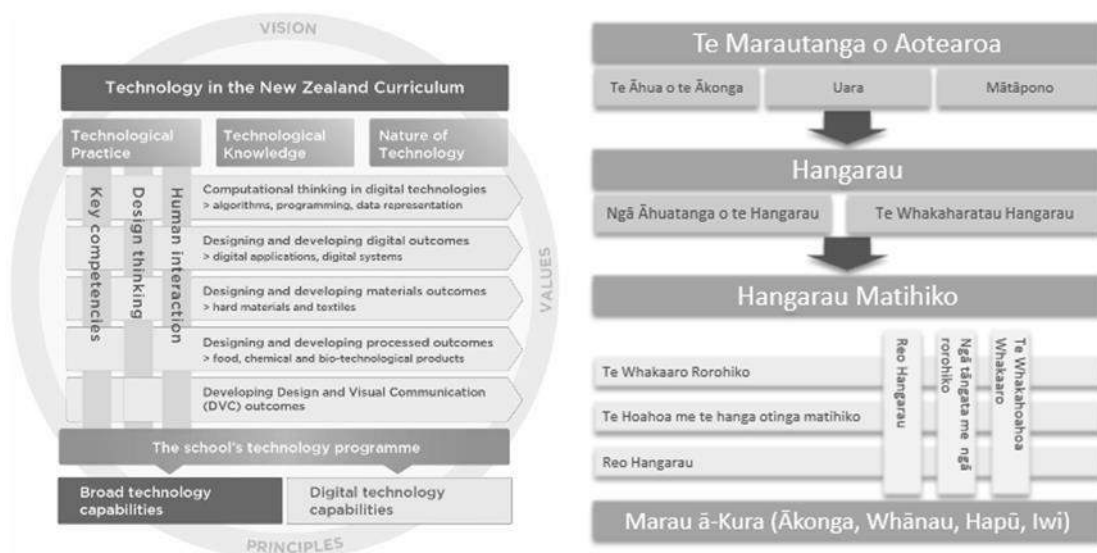


Figure 2. First draft proposed models for technology education and hangarau matihiko

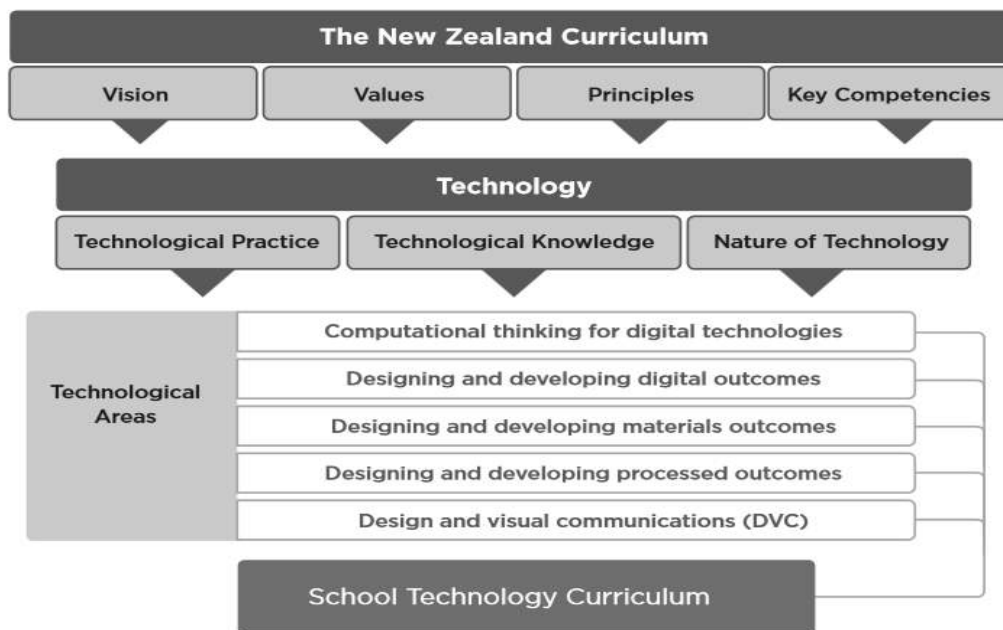


Figure 3. The released draft structure of technology

A carefully planned and delivered consultation process followed to ensure both the English speaking and Māori medium sectors could respond to the proposed changes to the curriculum. The Ministry of Education commissioned the process which included questionnaires, workshops, written submissions, analysis and collation of all feedback. This work culminated in the release of a report in November 2017 (Martin Jenkins, 2017). This report indicated that the proposed changes are seen as a positive move, although questions were raised about progressions, implementation at Year 9 &10, links to Te Whāriki (early childhood curriculum) and applications in partnership schools and other alternative schools such as Steiner schools (Martin Jenkins, 2017).

Another project undertaken by the working parties, with commissioned ‘process’ experts Educational Technologies, was school trialling of aspects of the new strands: ‘computational thinking for digital technologies’ and ‘designing and developing digital outcomes’, and subsequently writing of the draft progress outcomes of which there are eight for each strand. These proposed outcomes were also published in the draft curriculum (Ministry of Education, 2017a).

The CAG report (2017) wrote 43 recommendations related to each of the working groups which offered useful comments for the Ministry of Education. A number of these recommendations are worth mentioning, as the final revised technology curriculum was released in December 2018. These are that:

- consultation needs to continue alongside research, piloting and implementation
- there is need for greater visibility of Te Ao Māori and Te Tiriti in the Learning Area Statement and Progress Outcomes but warns against the shallow, decontextualised inclusion of Māori concepts
- to avoid confused implementation and reporting, and unintended future consequences, that the other three technological areas replace AOs with Progress Outcomes OR that the language of Progress Outcomes/AO be clarified to reduce confusion for teachers
- all language in the curriculum that is likely to date be removed (e.g. LAN, PC)
- a dedicated PLD plan to bring current and new teachers (i.e. teachers in training) up to speed is developed in consultation with the Education Council of New Zealand
- Digital Technologies is part of a curriculum area in its own right with its own content, understandings and capabilities, and not just a pedagogical vehicle/tool for delivering the whole curriculum
- that a new name for technology that incorporates the word ‘Digital’ be implemented and suggests Digital and Materials Technology as one possibility.

The final technology curriculum model, released in December 2017 and to be implemented from 2018 is outlined in Figure 4. It indicates that three of the technological areas Designing and developing materials

outcomes, Designing and developing processed outcomes, Design and visual communication will continued to be organised and assessed around existing achievement objectives. Process Outcomes, used to guide and assess for the remain two areas Computational thinking for digital technologies, Designing and developing digital outcomes (Ministry of Education, 2017d) are also to be underpinned by the original Achievement Objectives. Emphasis of the new curriculum is that students should learn new skills and knowledge for authentic purposes, to solve real life problems.

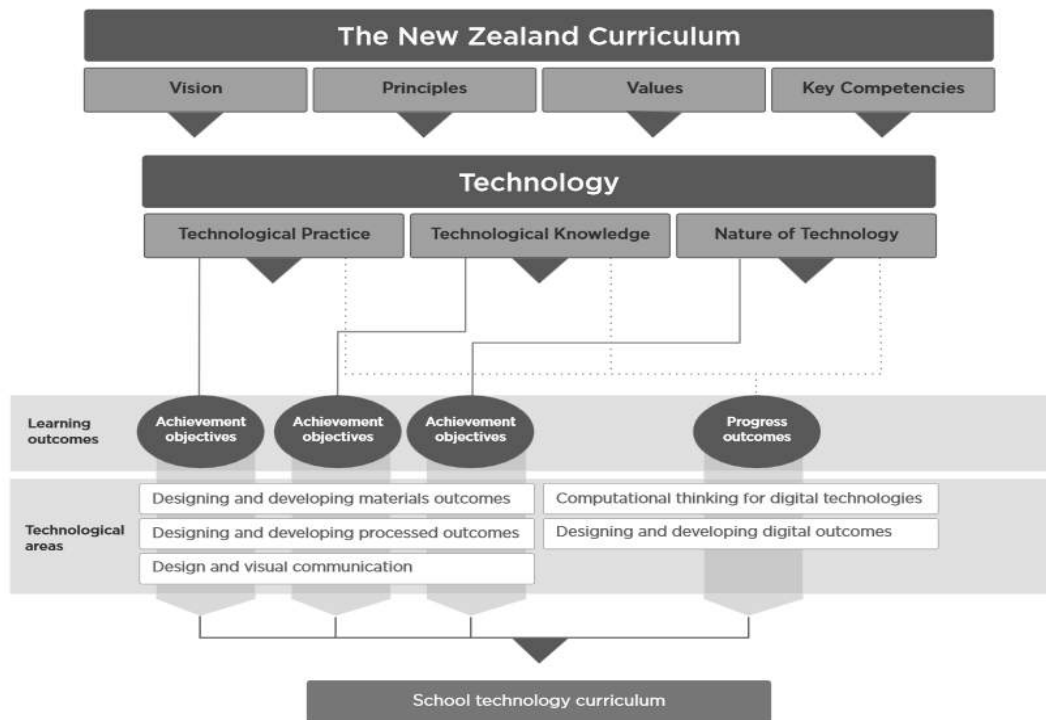


Figure 4. The final structure of technology (<http://nzcurriculum.tki.org.nz/The-New-Zealand-Curriculum/Technology>)

In December, the MOE announced a pended multimillion dollar contract to develop and implement PLD in digital technologies to 44 000 teachers over the next three years. Submissions were due in mid-December 2017, with the winning contract awarded in mid- January to begin in February 2018.

## 8. CONCLUSION

Over the last two years, the New Zealand Ministry of Education has undergone a number of very thorough consultation processes to determine firstly the place of digital technologies in the curriculum, secondly the structure of a proposed revised curriculum to incorporate digital technologies within technology and thirdly the development of the content of the proposed digital curriculum. The process has been transparent and rigorous with a large number of interested parties having the opportunity to engage with the process if desired.

Digital technologies, like technology education, quite purposefully teaches students to design and develop technological outcomes. This article presents the argument that digital technologies is well -situated within technology. Its incorporation into the curriculum will situate learners in a strong position to be digitally capable and literate citizens able to contribute productively to the digital economy.

There are however, three perceived risks subsequent to the proposed changes mentioned. The first is that the digital technologies component of the technology curriculum become a skills based curriculum as students come to terms with computer science and computation thinking skills and concepts. It is vital that teachers ensure that authentic contexts are used to situate student' learning and that the teaching of needs-based contextualised skills occurs. This requires deep knowledge and understanding of digital technology, technology education and related pedagogical content knowledge (PCK) and careful programme planning. The second

danger is that digital technology, with its increased presence will be perceived as more important than and replace materials and process technologies as teachers are increasingly pushed for teaching and learning time within a crowded curriculum. Again, well-informed programme planning and a teams-based approach within schools will ensure coverage of all aspects of the technology curriculum. The third risk is that public (in and out of the education sector) perception of digital technologies be misinterpreted as e-learning and or using digital technologies as a teaching and learning tool. It is hope that the extensive professional development programme offered will be extend not only to teachers of technology, but also to people in school management positions such as principals and senior managers. It is also important that initial teacher educators be included in PLD programmes to ensure student teachers are graduating with clear understandings of technology education including digital technologies. Vital on-going monitoring by the Ministry of Education and the Education Review Office with substantive PDL programmes for all teachers and student teachers offers the potential to mitigate these risks.

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# A Model for Food Literacy Education

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Technology can be described as what happens when humans transform items to meet their needs (de Vries, 2005). When food is a context for this analysis, rich tales of societal identity, change and development result. Previous attempts to analyse this interaction was an examination of the concept of food literacy (Royal Highland Education Trust, 2016, Vidgen & Gallegos, 2012). However, what constitutes an education for food literacy remains largely unexplored. This research identified what components could contribute to a food literacy education. A theoretical model was developed that references the technological capability and technological competencies that are required to develop a view of technological food literacy.

*Key words: Food literacy, food literacy education, technological literacy.*

## 1. INTRODUCTION

A central idea within technology education is that students will develop their technological literacy (Compton, 2010). In New Zealand education, student's technological literacy is developed through an exploration of technological practice, knowledge and the nature of technology (Ministry of Education, 2007). This paper will argue that to educate 21st century learners in food a deeper perspective on what constitutes food education within the technology education context is required. Consequently, this paper describes how students' technological food literacy could be developed.

An initial premise is that food can be considered as a technological outcome. Technology is defined as human activity that transforms the natural world to make it a better fit with their needs (de Vries, 2005, McGinn, 1978). If we view food as a technological outcome, then consideration can be given to the human activity that transforms an item into food by humans deciding to consume, prepare and eat the object. These transformational decisions provide the focus to consider food as a technological outcome.

The idea that food is technological may appear novel. Mitcham (1994) suggested a conceptual framework that describes if an object is technological in nature or not. Within this framework, an item is described as being a technological outcome if technological knowledge, artefacts, activity and volition have been combined in its production (Mitcham, 1994). If we view the idea of 'food' within this framework, people view an object and make a decision that it could become food. They then undertake technological activity and knowledge to develop the item into a food artefact. If we take an example of a mushroom. People view the mushroom, perceive it as food and wish to eat it. They then apply their knowledge (is this actually an edible mushroom or not) and activity (how to cook mushrooms) to turn it into a dish (a side of sautéed mushrooms at dinner) that they will consume.

Food is both technological in nature (as a product we may consume) and can also reflect the level of a person's technological literacy (indicated by the decisions and activity that underpin how the item has been prepared and processed into food). The influences on our food choices can also be influenced by environmental factors – such as the suitable growing conditions for produce, and the societal and familial influences of eating within a particular cultural pattern.

In an attempt to provide an over-arching definition of food literacy a group of food experts proposed a conceptual framework that they felt reflected this complexity. Known as the Giessen Declaration (Beauman et al., 2005) food, drink and nutrients and their interactions with other systems were considered. The Giessen Declaration has been viewed as a cornerstone to the idea of food literacy (Vidgen, 2013).

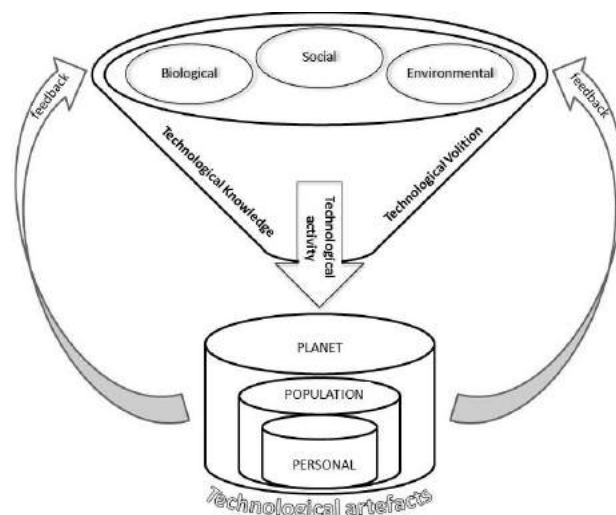
However while the Giessen Declaration defines food it fails to acknowledge the link with human interactions that would make it truly reflective of a technological outcome. In seeking to explore the concept of technological food literacy any definition needs to acknowledge this perspective on food. This research reports on the development of the food technology literacy model that embraces the rich complexity of food with the philosophical approaches of technology education.

### ***Explaining the Theoretical Food Literacy Model***

We argue that definitions of food literacy were inadequate and did not reflect the complexity of human’s interactions with food. A generic model interpreting technological food literacy was developed which acknowledges the principles expressed in the Giessen Declaration (Beauman et al., 2005) and the modes of technology (Mitcham, 1994). This theoretical food literacy model views the food world where, through deliberate design, humans work to create food solutions that meet the needs of particular people and populations while considering the resulting global impact such actions may have.

Food is seen as a system, in which a set of things work together in a complex, interconnecting network. The Giessen Declaration (Beauman et al., 2005, p. 783) identifies three dimensions of food systems as being “biological ... social and environmental” in nature. Utilising this description from the Giessen Declaration, our theoretical food technology literacy model shows these three systems of nutrition science as spheres at the top of the model, feeding into the theoretical food technology literacy model (shown in Figure 1). The Giessen Declaration (Beauman et al., 2005, p. 783) also suggests that new nutrition science is ultimately concerned with “personal, population and planetary health”. This is shown in the model as a set of nesting containers at the base of the theoretical food literacy model (Figure 1).

It is proposed that the theoretical food technology literacy model provides a way to show how food resources and technology interact. The rich complexity of the food world and the way humans use knowledge and volition on food systems means that a way of clarifying these connections is required for a deep realisation of food literacy. We assert that the philosophy of technology provides a framework to mediate with these dimensions of food. These technological connections and interactions are represented in the theoretical food technology literacy model (Figure 1) as two sides of the funnel in the centre of the diagram, where technological activity occurs the resulting food artefacts nest in the containers at the bottom of the figure.



*Figure 1. The theoretical food technology literacy model*

Note: The food systems and associated resources feed into the technological activity funnel, which produces technological artefacts that affect the person, populations and the planet. Feedback is also shown by the arrows. In this model, technological activity is represented by a funnel. Not dissimilar to different liquids flowing through a funnel, there is the potential for an infinite number of ways that the food systems and worlds can connect and interact with each other. These interconnections could have an effect that is fleeting or be of a more permanent nature. This activity is technological, as human activity mediates the connections. What is significant in this model is that the funnel is a visual metaphor for technological activity and potential change in the food as it tumbles through the funnel towards a technological food outcome. This outcome can affect the person or a population group as well as having a global influence. The nesting containers at the base of the theoretical food technology literacy model acknowledge this concept and suggest that the technological artefacts produced have an influence on people, populations and the planet. There is a feedback mechanism in the theoretical food technology literacy model indicated by the arrows that feed from the nested containers back to the funnel. These arrows acknowledge that the knowledge gained by prior actions can feed back into the theoretical food technology literacy model to provide valid knowledge formation that might inform future actions.

## 2. METHODOLOGY

### *Populating the theoretical food technology literacy model with experts' views*

The following research questions were posed to examine how food experts perceived food literacy and its educational development.

- What are the attributes of a food literate person?
- What components are deemed essential for a food literacy education programme?

Potential food expert participants were alerted to this research by email and invited to take part in the research. A homogenous sample of 24 experts from a range of food-related fields was interviewed. The homogenous sampling approach was used in order for a balanced range of viewpoints about food could be gained. The food experts were in specialists in a range of expertise that included food insecurity, the nutrition and medical fields, food scientists, food technologists, the chef trade, food teachers, food curriculum experts and food historians. The majority of these experts had participated in their fields for 10+ years and were identified by their work that was recorded in the public domain.

In order to provide the space to comment and share their opinions a Delphi methodological approach was implemented. The Delphi method is a forecasting method that uses a structured communication approach. These food experts were asked over a series of sequenced questionnaires so as to gain a consensus of opinion about what attributes and components were seen as essential for a food literacy education programme.

Initially each expert was interviewed using a semi-structured approach. The interviews were open-coded, then pattern coding was used to identify four themes about food literacy within which were 18 sub-themes. These sub-themes were then used in a Likert style questionnaire where the experts were asked to rate each theme on their essentiality in a food literacy education programme.

For example in the interviews the sub-theme 'knowledge of the origins of food' was identified. This was characterised by the food experts in the interviews as an essential component in a food literacy education programme because they felt students should have an awareness of:

"...where food has come from."

"...where the food originated."

Consensus was developed through two questionnaire rounds. Initially the interview responses were converted into statements that were ranked using a Likert scale that looked at the levels of how each statement was considered 'being essential' for food literacy education. Six statements were eliminated. The experts were then asked to rate each remaining statement as to how "absolutely essential" it was in a food literacy education

programme. In the second round the experts were able to see selected responses others had made in the previous rounds and reflect how their personal viewpoint related to the responses of the rest of the experts. Two statements were eliminated and consensus was achieved, identifying 10 components.

### 3. FINDINGS

#### 3.1 Experts' identification of essential elements of food literacy education

The final components of food literacy suggested by the food experts are indicated in Table 1. A pattern coding system was used to determine the common themes from the interview data. Initially four themes with 18 subthemes were identified. These were reduced in number through the Delphi process to provide the final 10 components of technological food literacy. The final themes and subthemes are identified in the first column descending the left-hand side. The final themes relating to the components of food literacy are arranged in three categories. The theme 'Disposition' referred to comments that suggested could be a motivation or an innovation that might be displayed by an 'ideal' food literate person. The theme 'Knowledge' refers to comments about situations where information or knowledge was applied or gained by a food literate person. The theme 'Skills' refers to where skills were practised by a food literate person.

The name of each component of technological food literacy is identified in the second column descending the page. Each component is a summation of the key ideas of the food experts that they shared when describing what could comprise and contribute to a food literacy education.

Table 1. Final list of suggested components of technological food literacy

<i>Theme and Subtheme</i>	<i>Component of Food Literacy</i>
<i>Disposition – Authentic</i>	<i>Food preparation from scratch</i>
<i>Knowledge – Culture</i>	<i>Knowledge of the cultural dimension and significance of food</i>
<i>Knowledge – Food systems</i>	<i>Knowledge of the systems that underpin food</i>
<i>Knowledge – Nutrition</i>	<i>Knowledge of health-giving properties of food</i>
<i>Skills – Critical thinking</i>	<i>Critical thinking and decision-making about food</i>
<i>Skills – Hygiene</i>	<i>Food hygiene</i>
<i>Skills – Shopping</i>	<i>Menu planning and food purchasing decisions</i>
<i>Skills – Tasting</i>	<i>Sensory experience of food</i>
<i>Skills – Cooking</i>	<i>Application of cookery skills</i>
<i>Skills – Learning</i>	<i>Use of literacy and numeracy skills</i>

Each component will now be discussed in turn.

#### 3.2 Food preparation from scratch

The food experts identified that encouraging students to develop a personal disposition towards enjoying and appreciating the challenge and satisfaction of food preparation was important. There was a particular emphasis that the food preparation should be from scratch, that is, from the combining of raw ingredients to produce a food item, rather than the assembly of a food item from a combination of pre-prepared food items:

“I think teaching people basic cooking skills and how to use raw ingredients and make food that tastes good is important.”

#### 3.3 The cultural dimension and significance of food

The food experts recognized that there was a cultural element to foods. They felt that students should be provided opportunities to recognise that food was an integral part of the daily life and was often a way the cultural dimension of a person's heritage could be expressed. One commented:

“When you look at the cultural and physiological function that cooking and food plays with human beings, it’s intricate and complex because food is not just about eating. It’s used for all sorts of other things in society ... communication, symbolism, tradition: it’s all sorts of things.”

### ***3.4 The systems that underpin food***

The food experts identified a variety of food systems. They particularly referred to:

“the development of the food supply including nationally and globally.”

“Knowledge of the systems that underpin food production, distribution, advertising, gardening and marketing.”

“The ability to read labels.”

### ***3.5 Health-giving properties of food***

When the food experts discussed their ideas about the health-giving properties of foods it was identified that students should be provided information about the nutritional qualities of food and how these can affect their health and well-being:

“Knowing how to create good health, but understanding that everyone is different.”

“All students should have the opportunity to learn how to feed and fend for themselves... in a healthy way for their sustainability in life.”

### ***3.6 Critical thinking and decision-making about food***

When the food experts identified this component, they wanted to empower students to be able to think critically about food information and then to be able to make decisions based on that information. The experts commented:

“Learning to question too, I think is very important, that they can look critically at the way in which food is advertised, the way in which it’s marketed, and what’s in it, like in the millions spent on advertising fast food.”

“...it’s basically assessing the information, validity of information in a world where information is hugely available.”

### ***3.7 Food hygiene***

The food experts indicated that skills concerning food hygiene rules that applied during food preparation, storage and service stages should make up an important aspect of a student’s technological food literacy. One commented that people needed to know the guidelines of food safety, particularly

“...knowing what they are [the food hygiene guidelines] and how to handle food regardless of who they are and what they are or where they are preparing it ... food-borne illness and contamination can generate illness and this can be a major problem.”

### ***3.8 Menu planning and food purchasing decisions***

These food experts felt that students should be provided with opportunities to practise menu planning and purchasing decisions about food. This included being given the opportunity to purchase food according to a budget or for a personal need:

“How to spend your money on food and balance your accounts.”

“They need to know how to plan ahead and to do it within a budget.”

### ***3.9 Sensory experience of food***

These food experts indicated that students should be provided opportunities of sensory experience with food, particularly taste. The experts commented that

“...you’ve got a huge population who have no idea about the things they can eat and what it should taste like.”

“Developing a palate and actually tasting a wide variety of foods is an essential.”

### ***3.10 Cookery skills***

The experts identified that students should develop skill competence in food preparation by being given the opportunity to participate in cooking lessons. One commented:

“All cooking skills are absolutely essential, far more important than an ability to play the violin, do karate, or swim four stroke.”

### ***3.11 Use of literacy and numeracy skills***

The experts identified that students need basic numeracy and literacy skills so they are able to process a variety of information about food from a wide range of sources. One commented:

“I would expect them to be able to ... read. We are assuming our clients are literate, but a trend I have started to notice is that illiteracy is an issue.”

And another listed a range of skills as being important:

“Being able to read. Or have some ability to follow a recipe. Yeah, being able to read, write and use maths, have some ability to read labels.”

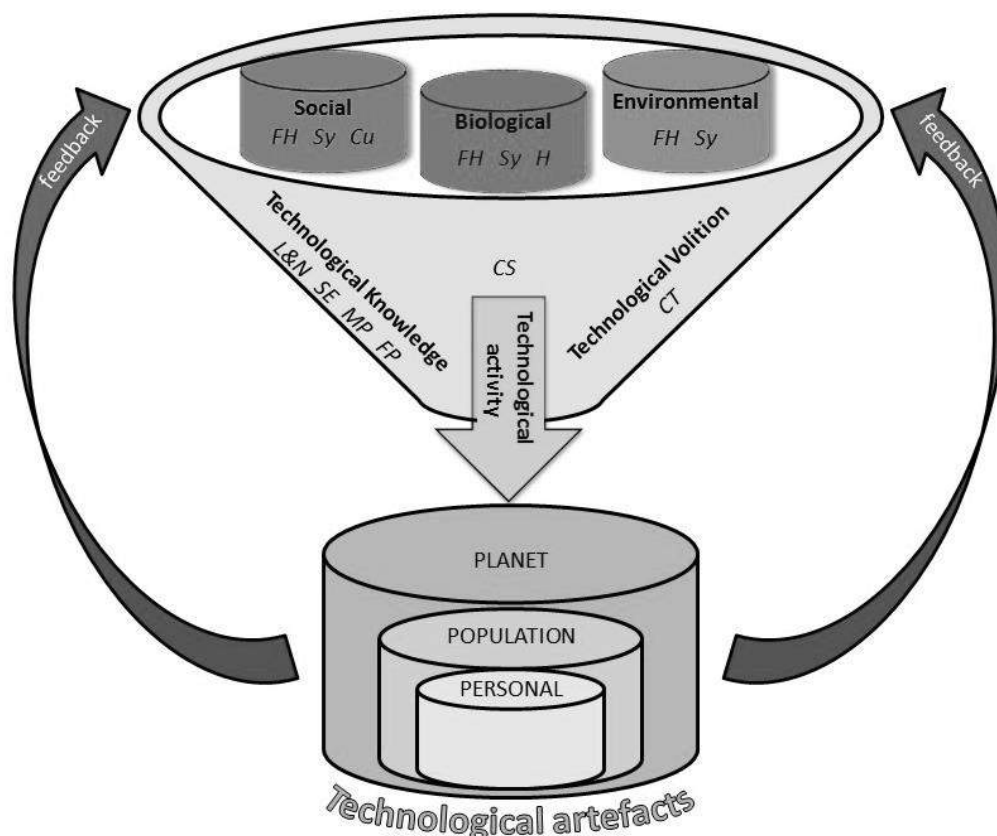
## **4. CONCLUSION**

### ***Populating the food technology literacy model***

These components of technological food literacy were used to populate the theoretical food technology literacy model in order to provide a workable model reflecting experts' views rather than reflecting a synthesis of the literature.

### ***The populated food technology literacy model***

This model (Figure 2) shows where the expert-originated components of technological food literacy have been located. To make the diagram easier to read, abbreviations for each of the components are used and a key provides more detail of each component.



Key of abbreviations for the components of food literacy

FH	Food hygiene	CS	Application of cookery skills
FP	Food preparation from scratch	L&N	Use of literacy and numeracy skills
SE	Sensory experience of food	Cu	Cultural dimension and significance of food
Sy	Systems that underpin food	CT	Critical thinking and decision-making about food
MP	Menu planning and food purchasing decisions	H	Health-giving properties of food

Figure 2. The populated food technology literacy model

To explain in detail, the three systems of food are shown as cylindrical shapes at the top of the diagram. The components of Food hygiene (FH) and Systems that underpin food (Sy) are contained within each system of food suggested by the Giessen Declaration. The Giessen Declaration identifies the social, biological and environmental systems as the dimensions that underpin new nutrition science in the modern age and provides clear examples of how they could potentially interact with and within each other in the food world (Beauman et al., 2005). This provides a much wider base from which to explore the issue of food in modern societies. The component Cultural dimension and significance of food (Cu) is included within the social systems dimension. The Giessen Declaration expresses the importance of social systems and identifies many social aspects of food, including how food contributes to the happiness of humankind (Beauman et al., 2005).

The Health-giving properties of food (H) component is located within the biological systems dimension. These locations are suggested within the wording of the Giessen Declaration, in which the social systems allude to “food cultures” (Beauman et al., 2005, p. 785) and the biological systems are indicated to be concerned with “the interactions of food and nutrition” (Beauman et al., 2005, p. 783).

The concepts of technological knowledge are populated with ideas about food literacy comprising the components Literacy and numeracy skills (L&N), Sensory experience of food (SE), Menu planning and food purchasing decisions (MP) and Food preparation from scratch (FP). The experts expressed a basis of practicality, activity and experience to these components. As a result these components are considered as expressions of technological knowledge. These components of technological food literacy utilise aspects of



tacit and explicit knowledge that Compton (2004) suggest is evident in the technological knowledge aspect of technology education.

The component of Application of cookery skills (CS) is allocated to technological activity. This component considers the skills of and about cookery. Technological activity is the mode through which things happen in our world and from which technological artefacts are produced. Within the populated food technology literacy model, an aspect of technological activity could be described as the use of cookery skills in the production of a technological artefact.

Finally, the ideas of technological volition are framed by the Critical thinking and decision-making about food (CT) component. This component encourages people to think widely and deeply about food and make decisions based on such thinking. Technological volition is the mode through which knowledge can be used to design products, processes and systems. Because of volition, an action may be undertaken as the result of the decision-making process about an aspect of food. Therefore, this education through this component could inform people's volition, or will and desire to produce a food artefact.

## 5. SUMMARY

This research focused on investigating the attributes of a 21st century technological food literacy in order to build a model of technological food literacy education. The development of the theoretical food technology literacy model is based on a premise that food is a technological outcome. This model illustrates how the essence of the philosophy of technology can be linked with the underpinning ideas about food and provides a way to visualise food literacy as a working model. The theoretical model was then tested with the ideas of food experts, to see if their ideas could be linked to these underpinning perspectives. The food experts were asked to indicate what they felt were the essential elements of food literacy. Their ideas have been statistically analysed and led to the identification of the most essential components of technological food literacy.

The resulting components of technological food literacy identify themes that illustrate both technological capacity and technological competencies with food. These components populate the theoretical model of technological food literacy. Such a populated model may indicate to food technology teachers what components could contribute to a 21st century technological food literacy education. These findings signal that a pedagogy for developing technological food literacy will entail more than the mechanisms of teaching cooking skills.

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# Food Education in the School Curriculum: A Discussion of the Issues, Influences and Pressures on the Teaching of Food

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In many countries food education in schools has become increasingly important due to concerns related to healthy eating, obesity, the place of 'home cooking' in changing life styles and food availability. Within the school curriculum elements of these concerns have in the past been addressed through the teaching of home economics, design and technology, food technology, science, geography, physical education, and personal, social, health and economic education (PSHEE). This paper explores what children should learn, understand and be able to do with regard to food in the school curriculum against the background of the English curriculum. It explores the tensions that exist between learning about food in the curriculum being seen as primarily concerned with providing life skills, providing a vocational pathway into catering and hospitality and an academic subject leading to study in higher education. It attempts to demonstrate how these tensions may be resolved in constructing a food curriculum that is appropriate for the 21st Century. It concludes by recommending an international study to identify and clarify some of the diverse issues, lessons to be learnt from successes and failures and justify actions points for the future of food education for young people.

*Key Words: food education, food technology, curriculum politics, curriculum development.*

## 1. FOOD IN THE SCHOOL CURRICULUM

Food was first taught as 'cookery' or 'domestic economy' in the elementary school curriculum in England in the mid to late 1800s for philanthropic or utilitarian reasons. It had a low status and aimed to teach the basic cooking skills to the working classes to raise the standard of living of the poor to improve their health and prepare their girls for low-paid employment. It was not until the early twentieth century that 'domestic science' was introduced for the more academically able girls in grammar schools focusing on nutrition, though it essentially remained a practical subject with little attempt to teaching underlying scientific principles (Rutland 1997, 2006; Rutland and Owen-Jackson 2015a). There were two main career opportunities leading from domestic science, one into household management or catering and another into teaching or advising people how to run their homes efficiently. Practical food lessons were also taught in housecraft as a non-examination subject for the less able girls.

In the 1970s, as a result of equal opportunities laws, food was taught to boys and girls within 'home economics', defined as 'the study of the needs of the individual in the community and the best use of human and physical resources in the context of home and family' (HMI, 1978). The food element included learning to cook, feeding the family in a domestic context, consumer awareness, nutrition and the sources and function of foods in our diet. A similar pattern can be found in the teaching of food in countries such as Australia (Turner, Wilks, 2016), New Zealand and the USA. It is still taught within home economics in countries such as Southern Ireland, Scotland, the Caribbean, Malta and Cyprus.

### *1.1 Food technology in England*

Following the introduction of the National Curriculum in England (DES, 1990) food teaching became 'food technology' under the umbrella of design and technology (D&T). The focus changed to 'food product development' in society in a wider context outside the home. The changes were quite profound and many food technology teachers, as they became now known, were confused and alienated by the requirements to 'fit' into the D&T curriculum.

It required basic knowledge and understanding of the science and technology of foods and their practical application in food product development. The D&T language was new, with terms such as designing, modelling, product analysis and specifications. Key areas of difficulty were:

- Product development and the concept of making ‘design decisions’ when developing a food product, rather than just having a recipe to follow.
- The term of ‘modelling’ in food as a ‘hands-on activity’ where pupils worked with and experimented with a range of foods ingredients and processes.
- An over emphasis, especially by examination boards, on detailed knowledge of industrial food equipment and processes.

Concerns were raised at this stage regarding the relationship between pupils ‘learning to cook’ and food technology. A Her Majesty Inspectors (HMI) report based noted that ‘confusion about the basic aims of food technology underlies some of the weaknesses in the curriculum’ (Ofsted, 2006, p 5-6). ‘There is a (more) fundamental clash, on the one hand, between teaching about healthy eating and how to cook accordingly and, on the other hand, developing food products to be marketed to meet consumer needs’. ‘In essence, a tension exists between teaching about food to develop skills for living and using food as a means to teach the objectives of design and technology’. Ideally, food technology should embrace an understanding of the properties of food materials and an ability to apply this to developing food products (Ofsted, 2006). This illustrated a fundamental difference of opinion between those who believed that children should be taught the ‘life’ skills’ of cooking and those who believed that a wider perspective is required.

## **2. RESEARCH INTO THE TEACHING OF FOOD: DESIGN AND TECHNOLOGY ASSOCIATION IN ENGLAND**

The initial thinking was triggered by an editorial in the D&T News (April 2008, p1) regarding the STEM (science, (design and) technology, engineering and mathematics) agenda in schools arguing that STEM is an important issue for schools in general and D&T in particular. The Association was exploring how textiles and food could make a significant contribution to the STEM agenda and agreed to support the research into potential place of food. The first phase would explore the development of a conceptual framework for food technology.

### ***2.1 Research Plan***

Data was collected for two sources, two food industry based conferences and interviews with a range of informants. The owners of a small, organic farm, the Head of the Centre of Food from Sheffield Hallam University, the Education Programme Manager from the British Nutrition Foundation (BNF), a National Manager from the Specialist Schools and Academies Trust (SSAT) and a Senior Food Technologist from Marks and Spencer.

The summary of findings highlighted a number of key issues:

- Changing life-styles and the increased consumption of ready meals and highly processed foods and the increased availability of supermarkets
- The need for pupils to understand the scientific concepts related to food and their application in a practical, visual context.
- Practical food-based activities should be linked to an understanding of nutrition and making healthy choices, knowledge of the sources of food and the functionality of ingredients.
- Knowledge and understanding of new technologies and processes, and their application and benefits would help the public make ‘informed choices’.
- The requirement in examination courses for knowledge of commercial and industrial practices was unrealistic. The focus should be on the principles and concepts of modern commercial production, rather than knowledge of large scale equipment and complex safety practices.
- Consumers should be aware of the protective role of food industry and government bodies in developing food policies. There is lack of scientific understanding of food issues by the public.

- National and international food availability and sustainability are key issues and will to become even more important in the future.
- Currently, it was not clear what will happen in schools if they focus on ‘learning to cook’ rather than wider issues of food technology.

An outcome from the research project was the development of conceptual framework for food technology:

- Designing and making food products
- Underpinned by an understanding of the science of food and cooking and nutrition
- Incorporating an exploration of both existing and new and emerging food technologies
- In the context of the sustainable development of food supplies locally, nationally and globally
- Incorporating an appreciation of the roles of the consumer, the food industry and government agencies in influencing, monitoring, regulating and developing the food we eat.

(Rutland, 2009)

### **3. DISCUSSION**

#### ***3.1 Obesity as a national issue in society***

The rising prevalence of obesity has becoming a major issue for England. The Foresight ‘*Tacking Obesities: Future Choices Project Report*’ indicates that over half the England adult population could be obese by 2050 (2007, p5). The government’s decision in to include an ‘entitlement to cook’ in the curriculum was in direct response to the growing concern about obesity in the population (DES, 2008). The ‘Licence to Cook programme’ ensured that pupils aged 11-16 years had the opportunity to learn practical cooking skills together with knowledge of diet, nutrition, hygiene and safety and wise shopping. It was intended that food technology, as a compulsory element of D&T, would be the preferred vehicle for the delivery of the ‘entitlement to cook’.

#### ***3.2 New technologies***

The importance of learning the role of government organisations, such as The Department for Environment, Food and Rural Affairs (DEFRA) and the Food Standards Agency (FSA) in protecting consumer interests and keeping the public informed about food safety and standards were highlighted. The widespread anti-science bias in the public mind, and in the media, had led to a slow take up of new technologies and a nostalgic view of traditional and inefficient practices (The Foundation for Science and Technology, 2008). The public, including children, lack a scientific understanding regarding food, have many misconceptions and therefore cannot make sound decisions (Rutland, 2009)

#### ***3.3 Food sustainability and global security***

There was a view that the world is moving towards a crisis and that we can no longer take food availability for granted (Rutland, 2009). There was a need to think about society’s impact on the environment and act accordingly. Pupils in schools need to learn about where foods come from, the food chain and how foods arrive at the table and understand the concept of Fair Trade food products. In addition, how it is possible to reduce the ‘carbon footprint’ of foods by using more locally produced ingredients.

#### ***3.4 Scientific understanding***

Pupils in food technology need to be able to make sound design decisions based on technical knowledge and understanding (Rutland et al, 2005). They need to experiment with foods and try things out so that they can apply basic scientific concepts, based on the chemistry of foods, in a practical context. Pupils in food technology need to understand ‘what happens if.....?’ so that they have the knowledge and skills to try out and develop new design ideas for their products. A reluctance has been noted (Rutland, 2009) to include theoretical food science in food technology courses, which would help pupils understand the ‘how and why’ of cooking based on the functionality of food. This would include knowledge of the basic concepts of food science applied in a practical ‘cooking’ context. For example, the coagulation of proteins though heating an egg, the gellatinisation or thickening of a starch based mixture though heating and stirring a white sauce or the use of

yeast as a raising agent in bread making. This approach would help develop a theoretical understanding alongside practical application.

### 3.5 Links between food technology and science

An important factor would be to strengthen the links between food technology and the sciences, especially chemistry. Collaboration between teachers of science and food technology to align the teaching of theoretical scientific concepts and understanding with practical activities would lead to greater understanding and capability. Encouragement for pupils following food technology courses to study chemistry and other sciences, would strengthen their knowledge and understanding and increase the numbers of pupils studying STEM based courses (Rutland, 2009).

### 3.6 The impact of a modern food technology curriculum

A modern food technology curriculum has the potential, if planned and taught well, to teach pupils much more than just the ‘skills’ of cooking. As an important component of D&T it is essentially ‘designing and making’ with food. Although as Layton (1993) stressed, the design parameters when designing and cooking (e.g. making with food) will be different to those with other materials and it will have its own vocabulary and frame of reference.

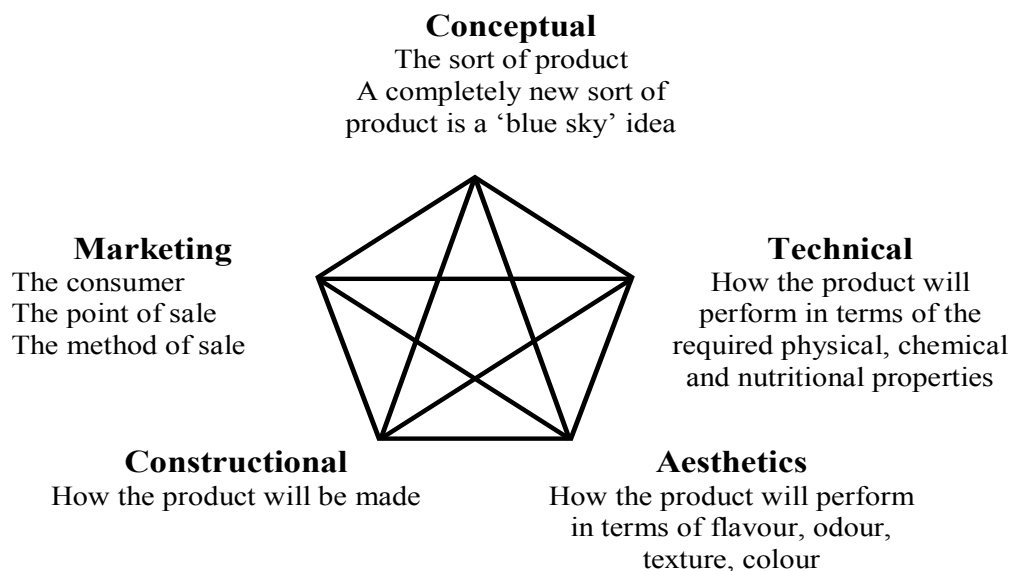


Figure 1: Modified design decisions model for food technology (Rutland, Barlex, Jepson 2005)

The model for design decisions in food (Figure 1) illustrates that pupils will learn to think in a systematic manner about their design decisions to modify or change the products that they design and made. It can be used by the teacher as a planning tool to ensure that the pupils make technical, aesthetic, constructional and marketing design decisions and show progress across a sequence of design tasks. Pupils can use the model to reflect on the design decisions they make when developing their product. Decisions may be made about just one or several different aspects in order to generate and develop a product to suit the set brief

Essentially, design and making with food is a problem solving activity. Pupils are set a brief, for example to develop a high fibre product to sell in the chilled cabinet of a supermarket, a main course for family with young children or a vegetarian, a low calorie ‘slimming’ product, or a high calorie product for an athlete. Younger pupils will have to deal with one or more criteria, for example specific ingredients or limited cost, but this can become more complex and include ingredients, cost, nutritional value, cooking methods, shelf-life or packaging. Initially, the design may be an adaption of an existing recipe, by adding some whole-meal flour to a basic short-crust based pastry mix or semi-skimmed milk instead of full-fat milk in a roux sauce (Rutland, Owen-Jackson 2015b). The learning environment for pupils aged 5-11 years will be a traditional classroom adapted with suitable resources to be safe and hygienic. Pupils aged 11-16 years will have specialist food rooms with a

separate area for experimental food work and for pupils aged 16 – 18 years access can be arranged to a science laboratory for some lessons.

#### 4. CURRENT SITUATION IN ENGLAND 2013–2018

The dual, sometimes conflicting, strands for the teaching of food became a key issue in the 2013 English review of the National Curriculum for D&T for pupils aged 5–14 years. Food was retained within D&T with the inclusion of term such as ‘ingredients’ and ‘food’; however there was a separate ‘cooking and nutrition’ section (DfE, 2013). This caused some confusion, whilst pupils were expected to design and make with food ingredients, working in home and wider industrial contexts; they were also required to ‘learn how to cook’, described as a ‘crucial life skill’. However, the curriculum document did not make clear how this aligned with the nature of D&T as a whole. Nor was it clear how learning to cook, without an understanding of ingredients, food science, and modern food technologies prepares pupils for their future lives or employment in the twenty-first century (Rutland, 2017).

Following the implementation of the new D&T curriculum, all GCSE and A Level subject content (DfEa, 2014) were reformed. A decision was made by the Department of Education (DfE) to teach a combined *GCSE Cooking and Nutrition*, later with a name change to *GCSE Food Preparation and Nutrition* (DfEa, 2015). This ‘built ‘upon the best of previous titles such as food technology, home economics and hospitality and catering.’ (DfEa, 2014: 6). Advice from a range of D&T subject experts, though who they were is not clear, was that a food qualification at this level should focus on ensuring students acquire a good understanding of food and nutrition together with excellent cooking skills (ibid: 6-7). The draft GCSE Subject Content for D&T (DfEb, 2014) did not include food as material in the context of designing and making. In practice, all the former food based curriculum pathways for the ‘life skills’ of cooking, home economics, hospitality and catering and food technology were to be addressed through one examination course. In addition, a separate food technology or advanced, higher level course for pupils aged 18 years would not be developed as a pathway to higher education courses, as a number of high quality vocational qualifications were available. Confectionary and butchery were cited as examples of such courses (DfEa, 2014).

#### 5. CONCLUSION

The Licence to Cook Programme (2008) in England raised the profile of food in schools. However, an emphasis on pupils ‘learning to cook’ at the expense of food technology content is a cause for concern. It can be argued that a broader approach would be more effective, considering the changes in life style where people are eating more high calorie, processed foods, are less physically active with an increased use of cars and modern, automated technological equipment in the home. These link, and relate to, our responsibilities for feeding ourselves and addressing the need for a global balance of supply and demand for food in the wider world (The Foundation for Science and Technology, 2008).

The question ‘Where does food fit into the curriculum?’ is not simple to answer. How, where and what pupils should learn about food are important issues. It can be argued that pupils wanting to learn to cook and develop ‘life skills’ could be offered courses which sit outside of the school examination curriculum. There are three distinct groups of pupils: those intending to follow food related courses in higher education, hospitality and catering or nutrition and dietetics. Should food be taught in one subject area or through a range of separate subject areas with academic, vocational, and general routes available? Or would a cross-curricular subject approach be more effective? Food studies could be within the science curriculum, but this might also lead to constraints on content and pedagogy. It could sit within humanities; history, geography and RE have managed to retain their individual identities under the ‘humanities’ umbrella and food could do the same. However, it could still be taught by food technology teachers as the content needs to include practical work, as it is this aspect of the subject that helps to make the theoretical underpinning more relevant, interesting and accessible (Owen-Jackson, Rutland, 2016). Food education has an important remit in the twenty first century and courses should be available in schools to meet all pupils’ needs and aspirations. It has the potential to be a vehicle for informing and enriching the lives of children in the 21st century in practical, intellectual and social domains (Rutland and Owen-Jackson 2015, Owen-Jackson, Rutland, 2016).

## 6. A WAY FORWARD?

This paper has, in many cases raised more questions than it has provided answers. It was for this reason that the author is currently working with a colleague in Australia on a book, *Food Education and Food Technology in School Curricula – International Perspectives*. The book will be published in Springer's book series: Contemporary Issues in Technology Education. The book draws together the perceptions and experiences from a range of international professionals with specific reference to food education and food technology in the school curriculum. It will present a variety of teaching, learning and curriculum design approaches across primary, secondary and vocational school education, undergraduate and post graduate initial teacher education programs and in-service professional development support. The authors include senior and middle managers and teachers in schools, university lecturers and pre-service teacher educators, researchers, continuing teacher development (CPD) trainers, curriculum advisers and external examination developers.

Individual chapters will reflect the author's background and country of origin, each of whom contributes a different and valued voice. In doing so, a reflective untangling will consider the purposes of food education and food technology, what children and young people should learn, understand and be able to do, why it is important and how it can be taught effectively. These narratives will, it is hoped, offer insight into some of the internationally diverse issues, lessons to be learned from successes and failures and action points for the future for food education for young people.

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# Project-based learning in technology education: implications of the digital era

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The paper addresses three issues related to the application of project-based learning (PBL) in the technological class. First, the need to integrate into PBL technological developments taking place today, for example, the extensive use of information and computer technologies (ICT), and the transition from physical to virtual systems and products. Second, the role technology education can play in developing students' computational thinking by linking technological problem solving to digital and computer applications, as well as teaching concepts from computer engineering and computer science within the context of solving problems and developing innovative technological systems and services. The intention is to expose students to the role computers can play in technological problem solving rather than teach structured courses in computer science or programming. Third, the difficulties and limitations in applying PBL in school, and the need to provide students with support in the first stages of project-based learning. It is important to tailor the scope and complexity level of the assignments to students' prior knowledge and skills, and provide instruction and support in order to reduce cognitive load and enable students to learn in a complex domain

*Keywords: computational thinking, physical domain, project-based learning, virtual domain*

## 1. INTRODUCTION

Project-based learning (PBL) has become one of the preferred instructional approaches for fostering meaningful learning and developing students' learning competences in all educational areas, and in science and technology education in particular. The rapid development of information and computer technologies (ICT) since the 1990s has provided educators and students with tremendous resources to implement PBL in school. However, the educational literature refers only little to issues related to the application of PBL in traditional schooling.

In this paper, I would like to address three subjects. First, the need to integrate into PBL the technological developments taking place today, for example, the transition from the analog to the digital world, and from physical to virtual systems and products. Second, the role technology education can play in developing students' computational thinking (CT) competences, which is of high priority for education in many countries. Third, the necessity to consider the difficulties and limitations in applying PBL in school, and the need to provide students with support in the first stages of project-based learning. A summary and concluding remarks will close this paper.

## 2. PROJECT-BASED LEARNING IN THE DIGITAL WORLD

The digital revolution affecting almost every aspect of our lives is also significantly changing technology education, and project-based learning in particular. In a previous paper (Barak, 2017), I pointed to a number of changes taking place in teaching technology, and electronics in particular:

- From handling with discreet components (resistor, transistor) to using readymade functional blocks such as amplifier, filter, or controller
- From building and testing circuits to using computer simulation
- From designing dedicated circuits to using embedded engineering and programmable microcontrollers
- From the analog to the digital world

- From hardware to software
- From physical to virtual products

In the past, we used to think that ‘real’ technological work had to do with working with touchable materials, using manual tools or machines, and building mechanical or electronic devices. Scholars in technology and engineering education in the US (Moye, Dugger, & Starkweather, 2014) referred to the notion of ‘learning by doing’ (Dewey, 1938) and defined ‘doing’ as “a tactile/hands-on process of technological problem solving starting with human needs and wants that leads to the principles of innovation such as designing, making/building, producing, and evaluating” (p. 24). Today, this definition required a slight update because project work in technology is increasingly consisting of the design and construction of systems and products that combine virtual and physical environments. For example, modern alarm systems for home or business are often computerized and connected to the network for remote observation and control. In the heart of a student’s work in such a project is system design and programming the microcontroller (virtual world), and connecting the digital camera, sensors, or siren (physical world). In robotics, students’ assignments might include using electro-mechanical components such as motors, gears and sensors to build the robot, program the robot and carry out physical measurements and mathematical calculations, for example, the distance, velocity and accuracy of the robot’s movement (Barak & Assal, 2018). Actually, robotics is gradually becoming a widespread platform for STEM learning by addressing significant portions of mathematics and physics (Sullivan & Heffernan, 2016).

As project work is taking an increasingly greater place in the virtual world, it is useful to examine the difference between the terms problem-based learning and project-based learning, which are quite often used interchangeably. Problem-based learning refers to investigating a problem in order to gain knowledge and understanding. In project-based learning, learners are not only required to study all aspects of a problem, but also to choose the ‘optimal’ solution and build a model, device or system designed to implement the solution. While problem-based learning focuses on the quality of the investigation learners conducted, project-based learning emphasizes the quality of the design processes and the final product the learners accomplished.

Since today, both the design process and the final product can take place in either the physical or virtual domain, it is becoming more and more difficult to evaluate what concepts and skills in technology and engineering the students gained by working on their project. There is room for evaluating the outcomes of students’ learning in terms of the objectives of technology education, and more specifically, the knowledge and skills students are expected to learn in the technological class. For example, Hacker and Barak (2017) conducted a study to compare the perceptions of American academic engineering educators (AEEs) and experienced classroom technology teachers (CTTs) about the engineering and technology concepts and skills essential for school graduates to succeed in the technological world. A consensus was found on items within five engineering and technology domains that are repeatedly referenced in the literature:

- Design
- Modelling
- Systems
- Resources
- Human values

The study also indicated that the most important competencies for high school students to learn are:

- Identify and discuss environmental, health and safety issues
- Use representational modelling to convey the essence of a design
- Use verbal or visual means to explain why an engineering design decision was made
- Show evidence of considering human factors when proposing design solutions

This viewpoint can inform technology educators about the objectives and required outcomes of project work in technology in which the students’ work process and project products are in either the physical or virtual world. Moreover, in the past it was common to distinguish between technology education (TE) – learning technological knowledge and skills, and educational technology (ET) – using technology for teaching and learning. Within the context of project-based learning that combines the physical and virtual domains, this

distinction is getting less and less clear. For example, when students use simulation software for designing electronic circuits or programming a microcontroller, at the same time this involves learning technology and using technology for learning.

### 3. FOSTERING COMPUTATIONAL THINKING (CT) IN TECHNOLOGY EDUCATION

It is widely agreed that the digital revolution, which started about a half century ago, has changed almost every aspect of our lives, for example, the economy, work place, transportation, communications and the ways we people spend their leisure time. It is also clear that education, including technology education, is changing at a much slower pace. We, therefore, need to examine what content and instructional methods in technology education we need to teach in order to better prepare school graduates for the digital world. In this regard, a concept that is attracting ever-increasing attention by educators and decision-makers worldwide is computational thinking (CT), which Wing (2006) described as “a way of solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science.” Wing noted that computational thinking involves some familiar concepts, such as problem decomposition, data representation and modeling, as well as less familiar ideas, such as binary search, recursion and parallelization. A number of authors (Wing, 2006; Barr, Harrison, & Conery, 2011; Barr & Stephenson, 2011; Yadav, Hong, & Stephenson, 2016) claimed that computational thinking is a digital age fundamental skill for everyone, just like reading, writing and arithmetic.

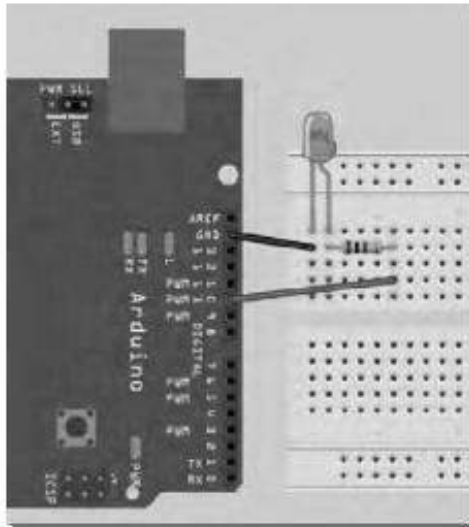
Programs for fostering computational thinking among school students have been published in many countries. In England, for example (Gov. UK, 2013), the national curriculum for computing aims at ensuring that all pupils:

- Can understand and apply the fundamental principles and concepts of computer science, including abstraction, logic, algorithms and data representation
- Can analyze problems in computational terms and have repeated practical experience of writing computer programs in order to solve such problems
- Can evaluate and apply information technologies analytically to solve problems, including new or unfamiliar technologies
- Are responsible, competent, confident and creative users of information and communication technologies

In a comprehensive paper entitled ‘Integration Computational Thinking into Technology and Engineering Education,’ Hacker (2018) writes that CT has been effectively integrated into subjects such as history, mathematics and science courses. In contrast, “there have been no analogous efforts to integrate CT in technology and engineering education, despite the opportunities for engaging learners in CT practice in the context of authentic technological challenges.”

According to Hacker (2018, p. 9), “Integrating CT within project-based technology and engineering contexts has the potential to significantly broaden participation for a large cohort of students (and their teachers) who might not be specifically interested in taking stand-alone computer science (CS) courses but are interested in designing solutions to technological and engineering problems.” This author presents a broad project for integrating CT in technology and engineering education, supported by the American National Science Foundation (NSF). The technological context is control systems and robotics, and the students work with components such as mechanical servo systems, motors, sensors and the Arduino microcontroller. This project, which includes curriculum development, teachers’ professional development and research opportunities, can certainly serve as an example of promoting computational thinking and problem solving in technology education.

In books and journals from recent years, one can find numerous ready-designed projects in Arduino and many studies on developing CT among students at all ages through Arduino-based projects. For example, McRoberts (2013) suggests the ‘first project’ in Arduino – a LED flasher, illustrated in Figure 1.



```
// Project 1 - LED Flasher
Int ledPin = 10;
Void setup () {
    pinMode(ledPin, OUTPUT);
}
Void loop() {
    DigitalWrite(ledPin, High);

    DigitalWrite(ledPin, Low);
    Delay(1000);
}
```

Figure 1: A LED flasher project with an Arduino microcontroller for beginners (McRoberts , 2013)

The LED flasher programming shown in Figure 1 is very simple. This can be the first step towards engaging students in more advanced projects that might also include reading data from sensors and performing close-loop control of technological systems such as light or temperature control. This learning environment aimed at teaching students basic concepts in computer-controlled technology and developing their computational thinking. Atmatzidou and Demetriadis (2016) describe the implementation of educational robotics activity in secondary school, focusing on the different possible impacts that the instructional approach might have on the development of students’ CT skills depending on their age and gender. In this study, the level of learners’ CT skills was evaluated at different times during the activity, with a focus on five key CT constructs (Wing, 2006): abstraction, generalization, algorithm, modularity and decomposition. Many studies relate to the development of computational thinking by programming in various environments, such as Scratch (Resnick et al., 2009; Marcelino et al., 2018; Scratch Jr (Estapa, Hutchison, & Nadolny, 2017), Lego robotics (Akin, Mericli, & Mericli, 2013) or Python (Molins-Ruano et al., 2018). In summary, the challenge for technology educators today is making project-based learning in technology an elite platform for fostering CT in school.

#### 4. THE NEED TO PROVIDE STUDENTS WITH GUIDANCE AND SUPPORT

According to the literature (Savery, 2006; Best, 2017), both problem-based learning and project-based learning intend to:

- Engage students in an open-ended question or task
- Provide a framework for authentic applications of knowledge and skills
- Engage students in collaborative learning
- Foster reflection in learning
- Prompt students’ learning skills and responsibility for learning, often defined as self-directed learning

For example, Mioduser and Bezer (2008) examined the contribution of project-based-learning (PBL) as a pedagogical means for supporting Israeli high-achieving students’ knowledge acquisition and problem-solving processes. The findings showed a significant increase in formal knowledge as measured by standardized matriculation exams, an expansion in the scope of technological knowledge acquired and implemented, and the scope of knowledge resources utilized for the projects. In addition, the study indicated a high level of overall performance regarding the set of design skills studied and a positive change in attitude towards technology and technological studies.

While educators widely agree about the advantages of PBL over traditional schooling, we must be aware of the difficulties and limitations of applying these methods within the regular school context. Hung, Harpole and Jonassen (2011) write that despite the popularity of PBL in educational settings, PBL generates a great deal of

scepticism and speculation among theorists. These authors mention that more than half a dozen meta-analysis and systematic reviews examined the effect of PBL on various aspects of students' learning outcomes, such as domain knowledge acquisition, problem-solving skills, self-directed learning, group processing, and social and psychological soft skills. However, the results from the meta-analyses were not conclusive, and even conflicting. If students are engaged in project work without sufficient preparation, only little learning is achieved in the project work, and students may be busy 'doing' with only little significant learning taking place (Blumenfeld et al., 1991; Barron et al., 1998; Barak, 2012).

Kirschner, Sweller and Clark (2006) criticize the notion of "minimally-guided instruction," for example, discovery learning, problem-based learning, inquiry learning, experiential learning and constructivist learning, because such learning methods are at odds with what is known about human cognitive architecture and processing. At the beginning of learning a new subject, instructional approaches that place strong emphasis on guiding the student learning process are more effective than the 'minimal guidance' approach (Hushman & Marely, 2015). The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide 'internal guidance.' Knowles (1975) put forward the term Self-Directed Learning (SDL), which describes a process by which individuals take the initiative in diagnosing their learning needs, formulate their learning goals, identify human and material resources for learning, implement appropriate learning strategies and evaluate learning outcomes. To foster Self-Directed Learning in PBL, it is important to tailor the scope and complexity level of the assignments to students' prior knowledge and skills, and provide instruction and support in order to reduce cognitive load and enable students to learn in a complex domain (Hmelo-Silver et al., 2007; Savery, 2006).

To engage students gradually in PBL, we developed the P3 Task Taxonomy, which distinguishes between three levels of student assignments:

- **Practice:** exercises and closed-ended tasks in which learners know the final solution in advance and can check if they arrived at the correct answer
- **Problem solving:** small-scale, open-ended tasks in which students might use different solution methods and arrive at different answers
- **Projects:** challenging open-ended tasks in which the students take part in defining the problem, setting objectives, identifying constraints and choosing the solution method

The P3 Task Taxonomy helped in designing students' tasks in a STEM-oriented course on the subject of sound waves and communications systems (SWCS) (Awad & Bark, 2016) and a robotics course for junior high schools (Barak & Assal, 2018). An earlier version of this taxonomy guided the design of students' tasks in a project for developing a system for computer engineering studies at the university level (Kastelan et al., 2014).

## 5. SUMMARY AND CONCLUSIONS

This chapter addressed three issues that accompany project-based learning in technology in the second decade of the 20th century. The first issue refers to integrating into technological problem solving the changes that are taking place in modern technology, for example, the transition from analog to digital technologies, and from physical to virtual systems and products. Actually, it is difficult to think today about students working on technological projects without digital or computing aspects. This digital-oriented learning environment goes hand-in-hand with the notion of 'doing' or 'making' as the core of technology education. In his chapter entitled 'The History and Prospects of the Maker Movement in Education, in the Handbook of Technology Education (De Vries, Ed., 2017), Blikstein (2017) writes:

"The maker movement in education has been a revolution in waiting for a century. It rests on conceptual and technological pillars that have been engendered in schools and research labs for decades, such as project-based learning, constructivism, and technological tools for 'making things,' such as physical computing kits, programming languages for novices, and inexpensive digital fabrication equipment."

The example of the small project based on the Arduino microcontroller (Fig. 1) and the increasing use of robotics for STEM learning fits Blikstein's viewpoint well.

The second issue addressed in this chapter is the role of technology education in developing computational thinking (CT) skills among all school graduates. As already noted, Wing (2006) defined computational thinking as solving problems, designing systems and understanding human behaviour by drawing on concepts fundamental to computer science. Technology education can play a central role in developing CT by linking technological problem solving to digital and computer applications, as well as teaching students concepts from computer engineering and computer science within the context of solving problems and developing innovative technological systems and services. It is important to comment that fostering CT is not about teaching formal or structured courses in computer science or programming, which are not required or suitable subjects for all students. In robotics, for example, children in primary school can learn to program a robot using an icon-based programming application and get the sense of programming a device and using a condition, delay or loop. Children in high school can learn to program a robot or a microcontroller using a higher language, and acquire concepts from computer science such as variables, procedures, and data input/output. In summary, technology education can serve as an effective platform for fostering CT among students of all ages, a subject of high priority for the education system in many countries.

The third issue discussed in this paper concerns the limits of applying project-based learning in conventional schooling. One hardship is that project work requires students to invest considerable effort and exhibit a strict learning discipline. We have seen that at the beginning of learning a new subject, students need instruction and support, while instructional approaches based on ‘minimal guidance’ or ‘discovery learning’ are effective only after learners have gained basic knowledge and skills in coping with a new subject.

## 6. CONCLUDING REMARKS

In Israel, there is a strong tradition of combining project-based learning in teaching technology and engineering in high school in areas such as electronics, mechanics and computer engineering. In light of the difficulties observed in school, as discussed in this chapter, a group of experts in technology education from academia and the Ministry of Education have formulated a reform in PBL. In the new method, high school students will start by preparing a ‘mini project’ in Grade 10, continue by preparing a ‘medium project’ in Grade 11, and finish by preparing a summative comprehensive project in Grade 12 towards the end of high school. The students’ work processes and outcomes will be documented online over three years. I hope to present the findings from applying the new program in future PATT conferences.

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# Multiple Design Representations to Foster Idea Development

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For young people to lead economic development in Ireland it requires young people to value and expand their capacity for creativity, innovation, and effective teamwork; all skills evident during a problem solving process. To support young people, the educators must grasp an understanding on how to support their students at secondary school level in the context of idea generation and development. Research evidences that this is a problem for both teachers and students, and is not solved only with curricular changes, but requires training and support. Added to this, educators often struggle to support their students in exploring more ideas after their initial ideas are exhausted. In addition, the assessment-driven dominance of the Irish second level education system may be impeding ones capacity for creative idea generation and development toward cultivating innovation. In this study, involving forty-three Technology Education trainee teachers, we sought to identify opportunities to foster idea generation using multiple design representations, such as idea sketch, and design development model. Over a 12-week period, the participants were individually tasked with a simple design project, which led them to generating an average of 30.7 ideas (max 34 ideas) across a range of representations. The ideas across the range of representations were traced to determine the impact on participant's idea development focusing on early attachment to initial ideas. The results from this study suggest that participants benefitted from engaging in multiple design representations as it supported their creative idea development by overcoming early attachment to initial ideas. The participants were more open to using and learning from multiple design representations to foster idea development. Through the use of multiple design representations to foster idea generation it has the potential to facilitate distinctiveness and diversity in educators' creative capabilities. This could potentially develop their own design pedagogical content knowledge, which could help educators teach with a design process.

*Key Words: Idea Generation, Design Representations, Cultivating Innovation, Idea Development.*

## 1. INTRODUCTION – CULTIVATING INNOVATION

For young people to lead economic development in Ireland it requires young people to value and expand their capacity for creativity, innovation, and effective teamwork; all skills evident during a problem solving process. These skills can be supported at secondary school level through the systematic approach of a problem solving design process. A systematic approach is required, as without scaffolding, novice designers often do not generate multiple solutions when facing design problems (Welch, 1998; Welch, et al, 2000; Crismond & Adams, 2012). During a problem solving process, idea generation and development are often areas of difficulty for teachers and students due to a lack of awareness of strategies to support the exploration of other solutions that are different from one's initial ideas (Cross, 2001; Sachs, 1999). In addition, there are concerns in relation to implementing textbook-based or assessment-driven design process models that do not fully represent the space of design learning (Adams, Turns, & Atman, 2003; Mosborg et al., 2005; Crismond & Adams, 2012). When exposed to a design problem, designers need a vast range of ideas (Crismond & Adams, 2012). However two issues often arise during ideation; ideas are in short supply (Adams, 1986), and fixation (Jansson & Smith, 1991), or the exploration of more ideas after their initial ideas are exhausted, to name a few. This ideation difficulty is not solved only with curricular changes, but requires training and support. In addition, the assessment-driven dominance of the Irish second level education system may impede ones capacity for creative idea generation toward cultivating innovation.

To cultivate innovation, one must firstly demonstrate creativity. Demonstrated creativity can be identified with respect to various aspects, such as fluency, flexibility, elaboration, and originality, to name a few (Guilford, 1956; Torrance, 1966, 1974, 1990). Creativity must be supported during ideation to ensure the problem idea



can be executed to an innovative solution. Studying creative design is seen as problematic because there can be no guarantee that a creative ‘event’ will occur during a design process, and because of the difficulty of identifying a solution idea as ‘creative’. However, in every design project creativity can be found—if not in the apparent form of a distinct creative event, then as the evolution of a unique solution possessing some degree of creativity (Dorst & Cross, 2001). Design activity includes cognitive activities such as thinking, imaging and decision-making, and psychomotor activities such as information gathering, sketching, and model-making (Pedgley, 2007; Evans & Pei, 2015). There are many tools, practices, processes, and methods to nurture and foster creative problem solving. These tools, practices, processes, and methods must be accessible, serve as inspiration, support ideation, facilitates testing and iteration. However, the difficulty and daunting task may arise for a novice designer, such as an educator, due to experienced designers solving problems using familiar and preferred tools and tactics with a process they have developed with experience (Crismond & Adams, 2012).

## 2. DESIGN PROCESS TO SUPPORT DESIGN IDEA REPRESENTATION

To cultivate an understanding for innovation in an educational setting, with educators and students as novice designers, a systematic approach is required to support a problem solving approach (Crismond & Adams, 2012). A design process is one such systematic approach. However there are many models of a design process each representing different practices, purposes and perspectives (Wynn & Clarkson, 2017). In the Irish Post Primary education system, the State Examination Commission predominately steers educators toward a dominant design process. One example of such process is illustrated in Figure 1. This assessment driven process often lends to ad hoc design practice, which is not fault of the model (Figure 1) but due to the lack of understanding of supporting strategies.

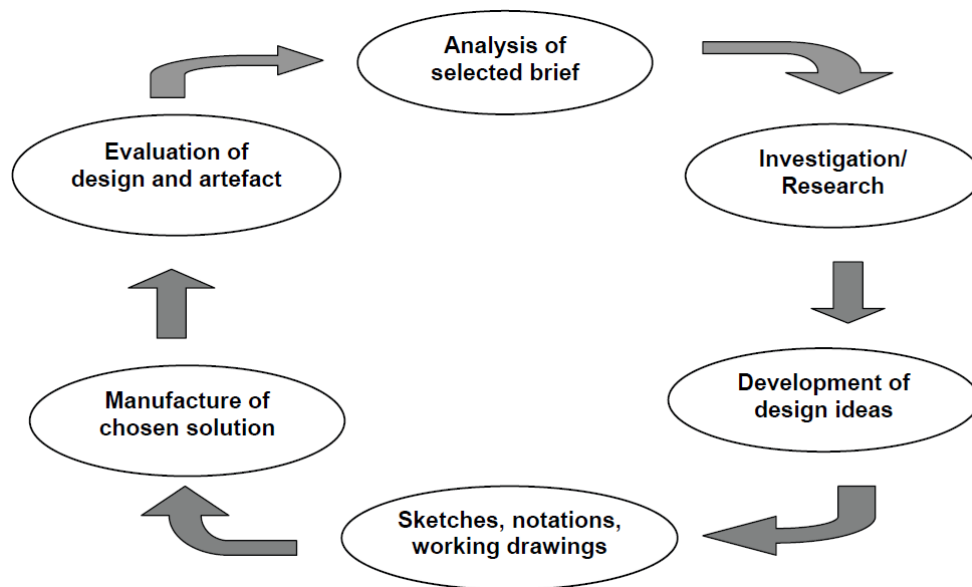


Figure 1. State Examination Commission advised design process for Materials Technology (Wood) (SEC, 2018).

According to Takeda et al (1990) “design is not a simple mapping process but rather a stepwise refinement process where the designer seeks the solution that satisfies the constraints” (Takeda, et al, 1990, p. 39). This iteration during ideation allows for the ideas to be further elaborated and detailed in high fidelity prototypes and computer aided modelling. Many professional design practitioners design thinking and practice, such as the IDEO approach represents a “system of overlapping spaces rather than a sequence of orderly steps” (Brown & Wyatt, 2009, p. 32). Crismond and Adams (2012) highlight that “Informed designers agree with statements about how ‘Design is iteration’” (p. 769) and that rarely the first idea is the right idea (Crismond & Adams, 2012)

Each stage of a design process represents the intended actions to be carried out at a specific phase of the design process. A design process is often regarded as an iterative process that evolves the design concept(s) from one representation to another, gradually representing a more detailed solution to a problem. The number of concept features increases as the design process evolves, thus addressing the problem specifications. The

representations are driven by the designer, based on preferential style and also how best to communicate the concept features. According to Römer, et al (2001) “it is still not clarified in which way, to what extent and with what effects sketches and models are already used in professional practice” (pp. 478). Thus this lack of clarity requires novice designers to represent their concepts in a range of representations, which have varying impact and use. This study sets out to investigate the impact of a range of representations by novice designers toward reaching an optimal design solution, acknowledging that a design solution is never complete.

For this study, the design activity was framed in the context of a problem solving process (Figure 1), which facilitated the multiple design representations:

- Analysis of the design task statement and generation design brief.
- Initial ideas in relation to the design task statement and/or design brief.
- Investigation/research relating to the design task statement and/or design brief.
- Development of design ideas, their evaluation and preferred solution.
- Sketches, notations and working drawings required for the completion of the preferred solution.
- Realisation relating to the experiments, planning, and execution of artefact.
- Evaluation of the design, its completion and the finished project.

The process was used in this study to support novice designers, as the iterative approach by experienced designers involves a similar process which is practiced with flexibly and supporting strategies to achieve a successful solution (Crismond & Adams, 2012).

This study primarily focuses on the multiple representations from initial ideas and developed ideas toward a proposed solution and realisation execution.

### **3. IDEA GENERATION AND DEVELOPMENT THROUGH VARIOUS REPRESENTATIONS**

#### ***3.1. Idea generation and development***

Design activities should involve intuitive (Taura, et al, 2017) and reasoned, higher order discursive approaches, during idea generation and development. To spur initial idea generation the problem should facilitate divergent thought. Idea development is facilitated by divergent and convergent thought based on the problem criteria or specification. Both divergent and convergent thought are required for creativity. It is important that novice designers do not fixate on their initial idea but develop a quantity of ideas early in a design process, as this leads to better design outcomes (Perttula & Silpa, 2007). However, developing a quantity of unique or progressive ideas is often an issue for many second level students. Therefore iterating on design ideas via multiple representations may push the designer to drive beyond their initial ideas toward exploring a range of ideas. The mixed media (sketched, model, etc.) during multiple representations also facilitates reflection on ideas from various perspectives.

#### ***3.2. Multiple design representations***

Viswanathan et al., (2016) highlighted the manner of representing external examples, as either sketches or prototypes, influences the amount of creativity and fixation. Representing external examples is also termed idea capture, in which ideas need to be captured in order to document them so they can be communicated to others or set aside for future use (Kirk, 2005). Multiple design activities to nurture typical design based experiences are required to support novice designer’s capture and iterate their initial idea generation toward progressive developed ideas. In the early stages of a design process little investment is given toward initial ideas. These initial ideas may be captured or represented via sketches and simple physical models to externalise ones thoughts. Similarly these physical models representations have often been named as being essential for successful idea development (Römer, et al, 2001). This relates to the lack of understanding on strategies to support ones design process approach (Cross, 2001; Sachs, 1999). There is a fear of failure and necessity to validate ideas (Brown and Wyatt, 2010). In addition, there is a lack of empirical evidence in the context of the way, the extent and the effects of sketches and models used in professional practice (Römer, et al, 2001). Table 1 represents the descriptions for a range (11) of multiple design representations included in this study. Intuitively reflective critique in ideas occurred for each representation, which is not the focus in this study. It is acknowledged that between each iteration representation student’s ideas may have undergone idea selection or received refinement or evaluation with respect to the problem criteria to ensure the idea evolution stayed on

task toward an optimal solution. It is also acknowledged that the sequence of such representations is not explored. Many studies have explored the sequence of idea development by expert designers versus novice designers (Constable, 1994; Egan, 1999). Experts often approach conceptually first, then sketch, and then model. However, novices often skip sketching and create a model (Welch et al., 2000), mainly due to a lack of confidence in their sketching quality (Constable, 1994).

*Table 1. Multiple design representations.*

Representation	Description
1. Idea sketch 1	Represents initial design ideas intuitively generated
2. Idea sketch 2	Idea development of initial ideas (with DH)
3. Client idea sketch	Inspiration from and development of client design idea (with DH)
4. Sketch model 1	Redesign existing solutions (developed frame form)
5. Sketch model 2	Redesign existing solutions (developed current chair)
6. Referential sketch	Redesign existing solutions; range
7. Operational model 1	Develop refined idea
8. Design development model	Alpha prototype; low fidelity prototype(s)
9. Operational model 2	Refine prototype idea
10. Pre-production prototype	Beta prototype; parametric model
11. Production	Final idea manufactured

### **3.3. Tools to support ideation**

Design process models offer guidance to novice designers, but can also lack specific support due to the array of practices, professions and perspectives they represent. Thus design processes often require supplementary tools or approaches to guide, help understand, and nurture the novice designer. This lack of support, especially in the context of idea generation may result in novice designers not using specific and relevant approaches to support their idea generation and development (Ahmed, et al., 2003). For example, educators might encourage students to generate idea using brainstorming (Osborn, 1957), without specific instructions about how to do so (Kramer, et al., 2014). In addition, during the creative problem solving process the generation of numerous and diverse ideas may be limited by one's imagination and curiosity due to a focus on implementation (Seelig, 2012). The focus on implementation may result in students not realising their potential, and/or not exploring all possibilities. Additional cognitive challenges associated with idea generation highlighted in existing research include early attachment to initial ideas and stop considering alternatives (Ullman, et al,1988; Linsey, et al, 2010).

In this study, one tool, Design Heuristics, was used in conjunction with the multiple design representations to support idea generation and development. Design Heuristics are “cognitive prompts” that encourage exploration of a variety of solutions during ideation (Yilmaz, et al, 2010a; Yilmaz & Seifert, 2010; Yilmaz & Seifert, 2009). Design Heuristics provide specific approaches, which support the generation of multiple, diverse, and creative ideas (Daly, et al, 2010). Design Heuristics are packaged as 77 distinct easy-to-use prompts to guide the generation of new ideas or to transform an existing idea.

Design Heuristics have been empirically demonstrated as effective in helping designers generate possible idea solutions to address their design problems (Daly, et al, 2012; Yilmaz, et al, 2012; Daly, et al, 2011; Kramer, et al, 2016). Design Heuristics can be applied multiple times during ideation and in various combinations to produce a wide range of novel ideas. They support the generation and development of non-obvious, distinct ideas.

To support their use in classroom and design settings, each Design Heuristic is explained on a 4 x 6 paper card. On the front of the card contains a descriptive title and action prompt provide specific instructions on how to use the heuristic to build a new idea or to modify an existing idea. The abstract image depicts the heuristic graphically. On the back of the card depicts two existing products, one an award winning product, and the second a seating device. These two examples evidence that each Design Heuristic can be applied to both a range of products and to the same product category repeatedly. An example of a Design Heuristic card is shown below in Figure 2.

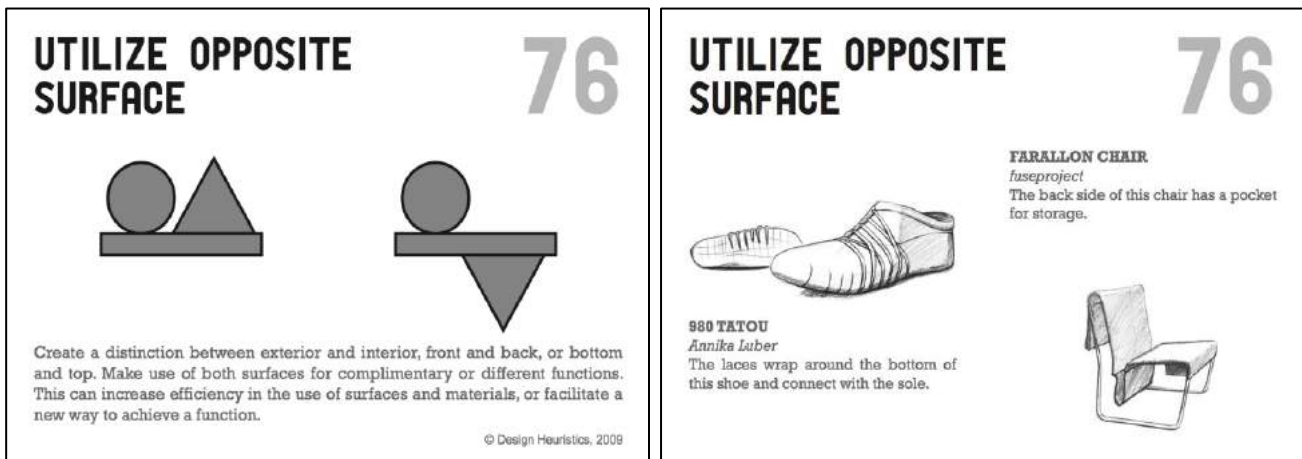


Figure 2. Heuristic Card Example: Utilize Opposite Surface

With the use of the Design Heuristic tool, a set of guidelines are proposed, but not required (www.DesignHeuristics.com). These guidelines include the following; Use a new card every time you want to generate a new idea; Combine multiple cards to generate a single idea; Use a single card to generate multiple ideas; Generate new ideas by applying a card to a previous idea; and, Use the abstract image or the examples to inspire ideas. These guidelines were informed to all participants after their initial idea generation (Idea Sketch 1), and were accessible for use in all multiple design representation categories subsequent to Idea Sketch 1. This paper only reports on the impact of the multiple design representations, not the Design Heuristic tool impact.

## 4. METHODOLOGY

### 4.1. Aim

This study set out to investigate the use of multiple design representations during a design process to foster idea generation and development. The impact of multiple design representations was explored through ‘early attachment’. This aspect was used to inform the feasibility of creative ideas through multiple design representations.

This study involved the following research questions:

- Investigating the use of multiple design representations to support students overcome early attachment?
- Investigating the use of multiple design representations to support students overcome fixation?

This study is not reporting how to develop a better understanding of how creative design occurs.

### 4.2. Research design

This study was situated in an existing Year 3 module, which aimed to highlight the importance of promoting individuality, innovation and creativity through design and realisation activities. In addition, this module provided trainee teachers (participants) with the opportunity to develop and apply a range of design and advanced processing skills in the context of Technology Education. Over a 12-week period, the module was structured cognisant of the problem solving process (Figure 1), which was facilitated by the application of multiple design representations. The module required participants to systematically follow the problem solving process (Section 2). For this study the focus is on ‘Initial ideas in relation to the design task statement and/or design brief’, and ‘Development of design ideas, their evaluation and preferred solution’. In the context of these two points, each participant documented their ideas in a process booklet that systematically guided participants through the problem solving process using multiple design representations as outlined in Table 1.

The module learning outcomes were constructed on a problem statement, which required each participant to individually solve the design task considering their client’s requests. The problem statement involved ‘design a seating device for a Second Class (age 8 year old) pupil to suit their size, fit / adjustable, seating that moves and serves a desired function which was based on client profiles’. Client profiles were sought by the module leader from a nearby Primary School, where 40 pupils generated an idea and supporting text outlining their ‘dream

classroom chair'. These Primary school pupils' ideas were distributed randomly to the module participants during the 'Client idea sketch' category. This Client design idea served two functions; to require the participants to consider a specific user, and to inspire ideation. An example of a Primary school pupil (Client) profile is illustrated in Figure 3.

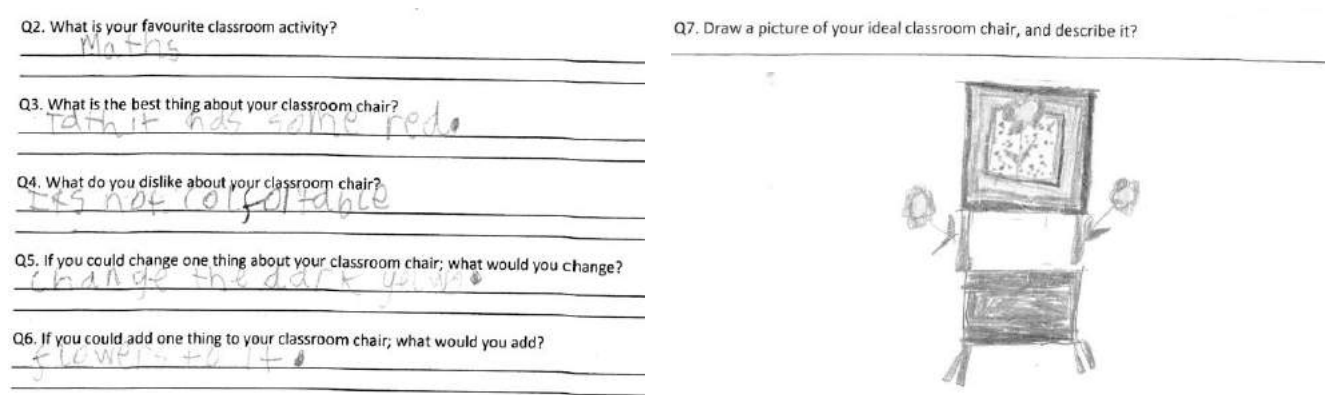


Figure 3. Client – Primary school pupils design requests (Q1 omitted as it contained Primary school pupil name).

### 4.3. Participants

This study involved forty-three Year three Technology Education trainee teachers. The gender breakdown in the study was 40 male and 3 female. The mean age of participants was 21 (StDev: 2.1). All participants had used a problem solving process in previous modules' coursework. Participants would have experienced the various design representations in isolated representations, but not as per the study systematic and iterative approach. The design task was new for all participants. All participants had no experience of using the Design Heuristic cards.

### 4.4. Methodological tools and implementation

The methodological approach was action research, which was intended to support the trainee teachers (participants) reflecting on their practice thus informing their future pedagogy for design-driven project work in Technology Education. The methods involved a process booklet which, systematically and iteratively guided participants through multiple design representations during their design process. The study tools included 15 Design Heuristic cards (random distribution), a process booklet, stimuli (Figure 4) and a PowerPoint presentation to guide the activities. The study was concluded with a post-survey.

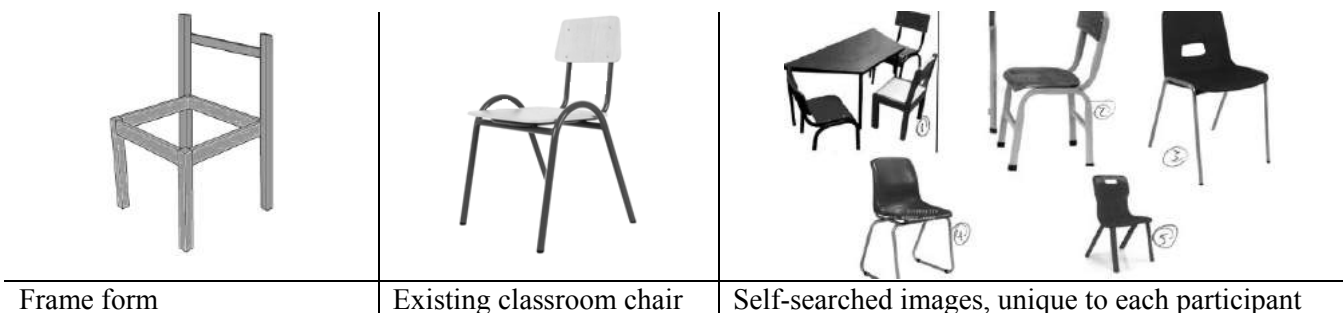


Figure 4. Idea generation and development stimuli

The study took place over a 12-week semester within the learning outcomes for the module. The main aim for the module was to provide and develop students' (educators) with the opportunity to develop and apply a range of design skills., in addition to highlighting the importance of promoting individuality, innovation and creativity through design and realisation activities. Each week involved a two-hour lecture, and complementary four-hour lab. All multiple design representation activities took place during the lecture and lab times. The study implementation was coordinated by two members of teaching staff. The pedagogical approach was underpinned by the module learning outcomes and a problem solving process (Section 2, Figure 1). The

multiple design representations were facilitated in an active learning approach whereby the trainee teachers externalised and documented their idea generation and development cognitive process through a range of ideation approaches (sketching, prototype, CAD, etc.). The data collection points were compiled in the process book worksheets (Figure 5), which were reviewed weekly during scheduled feedback sessions.

Sketch your initial idea 1 in the box below.

Concept Description: Describe the idea. What functions does it serve? What are the features, and details?

Concept Origin: Where did this idea come from? What influenced / inspired this idea?

Figure 5. Process book ideation worksheet example

Each process book worksheet had a different focus with respect to the multiple design representation categories. In addition, the stimulus varied for each representation category to support idea development. The implementation duration and details for each representation category are outlined in Table 2. It is acknowledged that external stimuli in the learning space environment could influence participant’s ideas during this study.

Table 2. Multiple design representations implementation details

Representation	Implementation timing	Implementation details
1. Idea sketch 1	Week 1 lecture	Participants were instructed after reading the Problem statement to document up to five ideas that intuitively entered their head / the ideas that automatically thought of.
2. Idea sketch 2	Week 1 lecture	After a brief introduction to the Design Heuristic tool, participants were distributed 15 Design Heuristic cards. Participants were instructed to use the Design Heuristic cards to develop five ideas from their five initial ideas.
3. Client idea sketch	Week 1 lecture	Each participant was randomly distributed one Primary school pupil (Client) design idea (Figure 3). Participants were instructed to generate five ideas that addressed / catered for the requests of this client.
4. Sketch model 1	Week 1 lab	Participants were shown a physical model of a skeleton for a basic seating device made from beech (25mmx25mm sections). This skeleton comprised of two front legs, two back legs extending to hold the backrest, and seating rails. No 'seat' was in this frame form. It served as the most basic model for a seating device, without any ergonomic considerations. Participants were instructed to redesign this existing solution 'frame form model' into five ideas.
5. Sketch model 2	Week 1 lab	Participants were shown a physical model of a current Primary school chair for a Second class pupil. This 'current chair' is illustrated in Figure 4. Participants were instructed to redesign this existing solution 'current chair' into five ideas.
6. Referential sketch	Week 1 lab	Participants were instructed to research existing product solutions on their mobile phone or other device and identify up to 5 images they wished to redesign. Participants were instructed to develop 5 ideas by redesigning the existing solutions.
7. Operational model 1	Week 1 lab	Participants were instructed to review their 30 ideas generated and developed in the previous categories and develop one refined idea that they intend to proceed to prototyping.
8. Design development model	Week 2 lab	Using their Operational model 1 refined idea, participants were instructed to create an alpha prototype; low fidelity prototype(s) to represent their refined idea with respect to size, scale and proportion. Participants were informed that this low fidelity prototype did not serve to determine how the design would be manufactured.
9. Operational model 2	Week 3 lecture and lab	Using the Design development model (low fidelity prototype) participants were instructed to refine their prototype idea and represent the refined iterated idea in sketch or other representation.

Representation	Implementation timing	Implementation details
10.Pre-production prototype	Week 4 lab	Using the Operational model 2 sketch or other representation, participants were informed to plan and create a beta prototype (parametric model), to include manufacture details, such as joints, etc.
11.Production	Week 5-12	High fidelity model representing final idea manufactured.

#### 4.5. Data analysis

This study set out to investigate the impact of multiple design representations during a design process to foster idea generation and development. The impact of multiple design representations was explored through ‘early attachment’. Analysis of ‘early attachment’ required tracing across the various multiple design representations. Thus the impact of using multiple design representations was determined based on the difficulties encountered during ideation, namely early attachment. Table 3 details the focus categories of the multiple design representations for data analysis. Each aspect is described in more detail in the subsequent sections.

Table 3. Data analysis focus on the multiple design representations.

Data analysis focus	Analysis rationale	Multiple design representation category
Early attachment	Initial ideas (Idea Sketch 1) in comparison to participants Final prototype (Production) to identity fixation on initial idea(s)	Idea sketch 1 Production
	Client idea in comparison to participant’s final production prototype to identity accommodation of client dream idea.	Client’s dream idea sketch (Figure 3) Production

##### 4.5.1. Early attachment

In the context of supporting participants overcoming early attachment, this required comparing participant’s ideas from Idea Sketch 1 category to participant’s final idea represented in the Production category; high fidelity prototype. The five ideas generated in Idea Sketch 1 are the participant’s initial intuitive ideas, straight from their head. Subsequent to this initial ideas comparison, tracing took place with respect to the Client’s dream idea sketch (Figure 3). The extent of early attachment was analysed on different levels; whole idea attachment, partial idea attachment, specific feature attachment, or no attachment. The identifying criteria for the different levels of early attachment are detailed in Table 4.

Table 4. Levels of early attachment.

Early attachment level	Description of criteria for analysis
Whole idea attachment	Participant made <i>little to no modification</i> to an early idea (Idea Sketch 1 or Client’s dream idea sketch).
Partial idea attachment	Participant made <i>minor modifications</i> to parts or components of an early idea (Idea Sketch 1 or Client’s dream idea sketch).
Specific feature attachment	Participant made <i>significant modifications</i> but maintained a feature from an early idea (Idea Sketch 1 or Client’s dream idea sketch).
No attachment	Participant generated a <i>new distinct idea</i> with no connection to an early idea (Idea Sketch 1 or Client’s dream idea sketch).

The following section evidences the results with respect to early attachment.



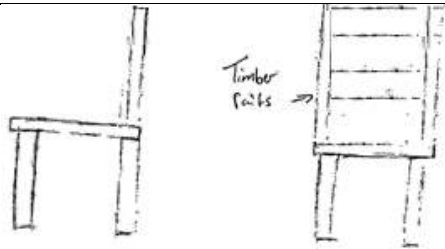

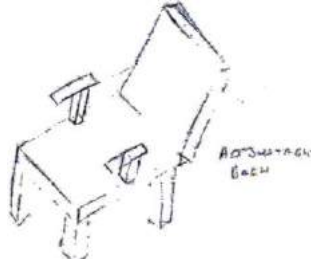

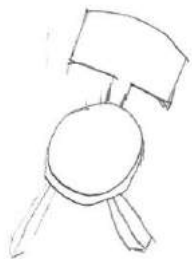

## 5. RESULTS

### 5.1. Overview

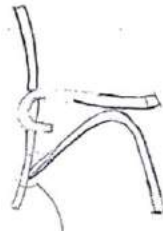
The results from this study set out to evidence the impact of multiple design representations (MDR) during a design process to foster creative idea generation and development. Across the 11 categories for MDR, participants generated and developed on average 30.7 ideas. The following sections will report results with respect to the use of MDR to support participants overcome ‘early attachment’ of initial ideas. The feasibility of creative idea development is explored through the use of MDR to overcome early attachment, which is a limiting issue during ideation.

### 5.2. Early attachment

Early attachment to initial ideas was explored initially by comparing participants Idea Sketch 1 five ideas with their idea represented in the Production category. From comparing all 43 participants Idea Sketch 1 initial five ideas to their Production, high fidelity prototype final idea, there was only seven participants (P2, P8, P14, P16, P19, P20, P26) who displayed varying levels of early attachment. Table 6 illustrates participant’s ideas representing one example from the four levels of early attachment. Only one participant P2, displayed whole idea attachment, whereby there was little to no modification between their Idea Sketch 1, initial sketch number 1. Participant 8, in initial idea number 3, evidenced a partial idea attachment through a minor modification by omitting the second arm rest component from the seating device. Participant 14, in initial dea number 5, evidenced a specific feature attachment through a significant modification of the seating device but maintained the circular seat feature. Though there are numerous examples for evidence in the contact of ‘no attachment’, on example is shown in Table 6 for Participant 19, initial idea number 5, which evidences no attachment generating a new distinct idea with no connection to any of their initial ideas.

Participant	Idea Sketch 1 - Initial sketch	Production – prototype	Levels of early attachment
P2, Idea Sketch 1, #1			Whole idea attachment: Participant made <i>little to no modification</i> to an Idea Sketch 1 initial idea.
P8, Idea Sketch 1, #3			Partial idea attachment: Participant made <i>minor modifications</i> to parts or components of an Idea Sketch 1 initial idea.
P14, Idea Sketch 1, #5			Specific feature attachment: Participant made <i>significant modifications</i> but maintained a feature from an Idea Sketch 1 initial idea.

P19, Idea Sketch 1, #5

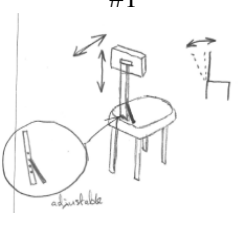
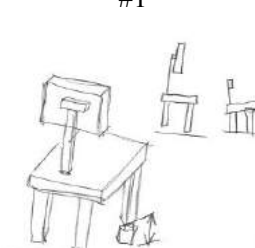
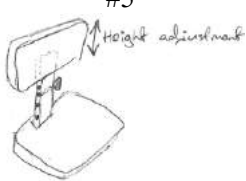



No attachment: Participant generated a *new distinct idea* with no connection to an Idea Sketch 1 initial idea.

Table 6. Evidence of early attachment from initial sketch to production prototype.

Overall, specific feature attachment was the predominant level of early attachment by participants. One case example, Participant 15, was explored in the context of specific feature early attachment analysed across the eleven categories of multiple idea representations (Table 7). Participant 15 generated five initial ideas in Idea Sketch 1. Evidence of early attachment was evident through a specific feature copy ‘rectangular flat back support’ and ‘vertical backbone support’ in Idea Sketch 1, idea #1. This specific feature was iterated on Idea Sketch 2, idea #1. This specific feature was iterated on again in Client idea sketch category, idea #5; rectangular flat-back support, however the vertical backbone support was modified with a height adjustment. This component ‘rectangular flat-back support’ was iterated on again in Sketch model 2 category, idea #5, however the vertical backbone support was modified to a twin support. So though there was evidence of early attachment, the multiple design representations facilitated the iteration of the participant’s idea through minor modifications to the parts or components.

Table 7: Participant 15 specific feature early attachment analysis

Early attachment level	Idea sketch 1	Idea sketch 2	Client idea sketch	Sketch model 2
Partial idea attachment ( <i>Minor modifications to parts or components of an Idea Sketch 1 initial idea.</i> )	#1 	#1 	#5 	#5 

This early attachment was also evident in the context of the Primary School pupils ‘dream classroom chair’ inspiration. In this context, zero participants evidenced whole idea attachment, five-percent of production ideas represented partial attachment, thirty-seven percent of production ideas represented specific attachment, and fifty-eight percent of production ideas represented no attachment. Table 8 illustrates participant examples, their respective client, and the level of early attachment to their client’s dream idea. The main rationale for zero participants evidencing whole idea attachment is primarily due to the ‘wild and ‘whacky’ ideas by the Primary school pupils’ (Client) dream classroom chair. Those that evidenced partial attachment (5%) iterated their ideas through a minor modification of parts or components from the pupils idea. An example of this is evident in P19’s Production prototype, which incorporates the spike feature components, which were modified from the extremity of the seating device to internally in the arm-rests for safety reasons. Participants that represented specific attachment (37%) in their Production prototype made significant modifications to the client’s idea, but maintained or incorporated a feature. An example of this is evident in P43 with respect to the animal feature in the pupil’s idea, and the yellow printed fabric as the seat upholstery. A great proportion (58%) of participants did not explicitly evidence their client’s idea in their Production, final prototype, representing no attachment. An example of this is evidenced in P2, which earlier demonstrated early attachment to their Idea Sketch 1, initial sketch 1, and thus evidenced no attachment to the pupil’s dream chair. A rationale for this no attachment by participants could be due to the abstract nature of some clients (pupil’s) dream classroom chair, the basic ideas portrayed by some pupils, or overly detailed or complex ideas (Table 9).

Table 8: Early attachment to Primary pupil's dream classroom chair.








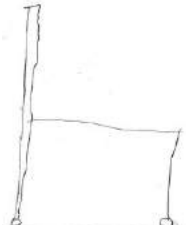
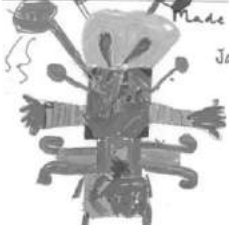
Participant	Client dream idea sketch	Production (final prototype)	Early attachment level
P19			Partial attachment
P43			Specific feature attachment
P2			No attachment

Table 9. Proposed rationale for participants no attachment to Client's idea

a) Abstract nature	b) Basic ideas with limited detail portrayed	c) Over-detailed or complex
		

## 6. DISCUSSION AND CONCLUSION

This study set out to explore the use of multiple design representations to foster creative idea development by overcoming early attachment. To cultivate innovation, one must firstly demonstrate creativity. Demonstrated creativity can be identified with respect to various aspects, such as fluency, and flexibility (Guilford, 1956; Torrance, 1966, 1974, 1990). It is acknowledged that one idea that is well thought through, and develops over time could have a huge impact. However expert designers have rarely found that their first idea is the right idea. Therefore the generation of a range of ideas is advised.

With respect to the quantity (fluency) of ideas generated and developed (mean 30.7) during this study, it suggests the participants benefitted from engaging in MDR in terms of generating and developing multiple ideas. Along with fluency, flexibility was evidenced with respect to participant's ability to overcome early attachment. In terms of early attachment, two categories of MDR were explored in this study; attachment to initial idea(s) and attachment to client's dream idea.

It was found that only one participant (P2) demonstrated attachment to their initial idea(s) in their final production prototype. Overall, to varying degrees, 84% of participants using MDR for idea development from initial idea(s) evidenced the ability to overcome early attachment. However, overall, specific feature attachment was the main magnitude of early attachment by participants. In this study specific feature attachment represented significant modifications to an idea, but maintained a feature. This form of idea generation and development aligns with the mechanism for practicing creativity. As Steve Jobs once highlighted; ‘Creativity is just connecting things’ (Dyer, et al, 2011). This is also highlighted by Duggan (2013) whereby the combination of knowledge or technology has led to many scientific discoveries and innovative products. Especially in the case for novice designers, it is acknowledged that designing from scratch is a rarity, and designing by synthesis is more feasible. As Duggan outlined; “creativity is synthesis itself” (Duggan, 2017, p 137).

In terms of early attachment to the client’s dream idea, fifty-eight percent of participants evidenced the ability to overcome early attachment, thus generated or developed a new distinct idea. Though the participants were not attached to the client’s idea, does not suggest that fifty-eight percent of participants did not consider and include the client in their design. It evidences that participants demonstrated the ability to overcome early attachment through MDR. In addition, as highlighted earlier (Section 5.2) this could be due to the abstract nature of some clients (pupil’s) dream classroom chair, the basic ideas portrayed by some pupils, or overly detailed or complex ideas. In terms of the forty-two percent of participants that displayed attachment of varying degrees, the extent of attachment predominantly evidenced specific feature, similar to initial idea attachment discussed earlier.

As outlined by Ullman, et al, (1988) those that practice early attachment to initial ideas stop considering alternatives. This practice thus limits their creative potential. In this study with the use of MDR participants were prompted to consider their idea through a range of media thus iterate on their ideas and push them further toward reaching their creative potential.

It is essential that novice designers do not fixate on one idea but develop a quantity of ideas early in a design process. However, developing a quantity of unique or progressive ideas is often an issue for many second level students. The implementation of multiple design representations in this study pushed novice designers beyond their initial ideas toward exploring a range of ideas. This study contributed to our understanding of using multiple design representations during idea generation and development. MDR fosters iteration and development of ideas during a design process idea development phase. Study outcomes revealed that multiple design representations support participants to overcome early attachment.

In conclusion, this study evidenced that multiple design representations’ use has the potential to facilitate distinctiveness and diversity in idea development thus enhancing creative capabilities and potential. MDR during this study evidenced that multiple representations supported by various stimuli supported participants to iterate on their ideas thus develop ideas further. Creativity must be supported during ideation to ensure the problem idea can be executed to an innovative solution.

Future research could investigate or compare the categories design ideas. In addition, it was evident that some participants synthesized or transfer their ideas from one multiple design representation category to another, which could be investigated in future studies.

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# Teaching young people to respond to a contextual challenge through designing and making – a discussion of possible approaches

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This paper will be in five parts. The first part will describe the role of contextual challenges in the new GCSE Design & Technology specification in England in terms of its intrinsic value as an assessment measure for the subject. The second part will describe a broad approach to tackling such a challenge. The third part reports on the results of a short questionnaire on SurveyMonkey to discover what teachers were might be doing to prepare young people for the contextual challenge. The fourth part will discuss the opportunities for ‘design for good’ as opposed to good design (Pilloton 2009) in such responses and report on the comments made by leaders in the field when considering responses to contextual challenges. The fifth and final part will make suggestions as to research activities that might be used to monitor the progress of the contextual challenge in the new GCSE Design & Technology as it is carried out from June 2018 with final submission in June 2019 and results available August 2019.

*Key words: Designing and Making, Design & Technology Curriculum, Design & Technology Assessment, Contextual Challenge.*

## **PART 1 THE NATURE AND ROLE OF THE CONTEXTUAL CHALLENGE**

In England some of the GCSE (16+) assessment for the school subject design & technology is carried out by means of a contextual challenge. This requires young people aged 15/16 years to explore a context, supplied by an Awarding Organisation (sometimes called Examination Boards), and through the exploration a) identify the needs and wants of people in that context, b) choose a particular need or want that they think is worth meeting, c) develop a design proposal to meet that need or want and then d) design, make and evaluate an artefact that meets this need or want. Details of the context are made available approximately one year before the course work describing the response to the challenge has to be submitted. This course work accounts for 50% of the assessment marks. The other 50% is achieved through a written examination.

The contextual challenge is a type of assessment known as Non-Exam Assessment (NEA), example contextual challenges provided by the Awarding Organisations are:

- Public Spaces  
*The sensitive design of public spaces can enhance users’ experiences and interactions with that space.  
Explore a space in your locality with the view to enhancing the users’ experiences within that space.*
- Improving living and working
  - How can living spaces also be used for a work environment?
  - How can objects be used for different purposes in a living or working environment?
  - How can an aid for people with disabilities improve their capacity to perform a given task?
  - How can we provide more protection for humans from the environment?

It is worth noting that a brief enquiry to six colleagues across USA, Israel, Australia, Finland and South Africa indicated that none have the assessment at 16+ years organised to include such an NEA but they reported many examples of similar work being carried out sometimes informally, sometimes as part of national or international competitions supported by business and industry, sometimes as part of the learning in the curriculum.

## **PART 2 A BROAD APPROACH TO TACKLING THE CONTEXTUAL CHALLENGE**

Design & technology teachers are used to teaching designing and making assignments so many elements of the contextual challenge will be familiar. A key feature of the contextual challenge is that at the outset students will NOT have decided what they are going to make. Some will see this is a mixed blessing.

For some students knowing at the outset that they were definitely going to make a particular artefact that will be useful to themselves and/or their family was a) a great motivator and b) a great simplifier for the task ahead. Others argue, ourselves included, that if the subject is to be seen as both academically and practically demanding then it is important that such an assessment begins with the exploration of a context to identify needs and wants of those within the context, leading to a statement of design possibilities that could address these needs and wants. At this stage the exact nature of the artefact to be designed is still uncertain. This identification of possibilities can be seen as the first phase of the contextual challenge. The second phase requires students to identify the most promising or feasible idea, develop and refine that idea to the point where there is enough information about the idea to draw up clear, unambiguous plans and to make the item. The third and final phase of the challenge is to evaluate the item from a variety of perspectives. This three-phase approach is summarised in Fig 1.

### ***Concerning phase 1***

One way to describe designing is a so-called triple S approach; you will be designing Something, for Somebody, in a Situation. Teachers may start a conversation with students by considering the 'something' and then moving on to the 'somebody' and the 'situation' as follows.

If this is the sort of thing you are designing, you need to think about who will be using it and where?

By asking who will be using it you can take into account the user's needs and preferences.

By asking about the situation in which it will be used you can take into account the situation of use.

In the contextual challenge this is turned on its head. The student will start with the situation or context and ask, "What problems or difficulties or desires do people have in this context?" Having identified these the next question the student asks is "What might I design and make that would help resolve these requirements?" This generates a set of design possibilities which the student then takes into Phase 2 for further consideration. One useful way to identify the problems or difficulties in a situation is to use the PIES approach to needs and wants (Nuffield Design & Technology 2000). PIES is an acronym for Physical, Intellectual, Emotional and Social. Exploring a situation to identify and categorise the needs and wants according to PIES is a useful and straightforward way to begin to develop a list of authentic design possibilities.



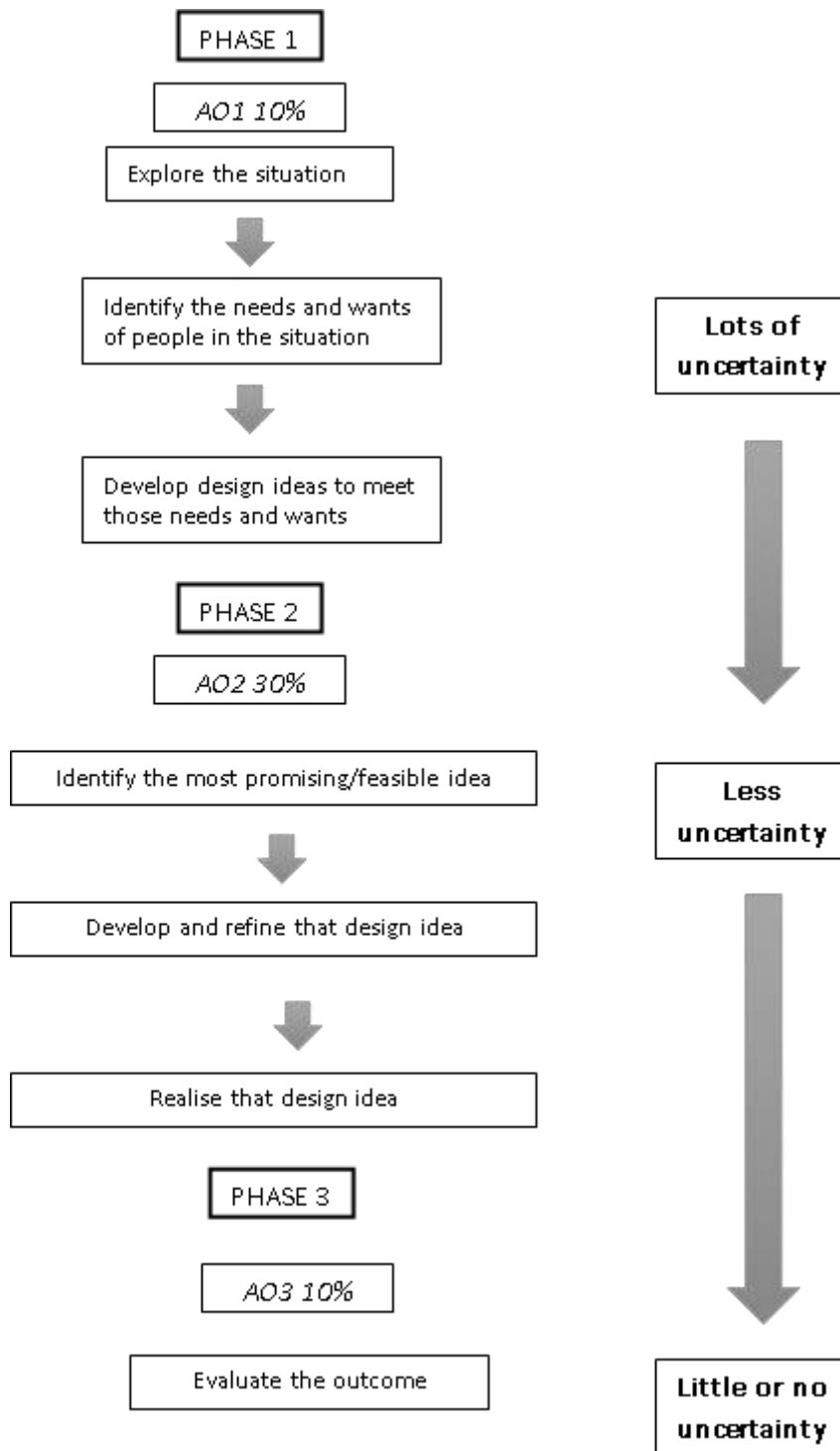


Figure 1. A three phase approach to the contextual challenge

### Concerning phase 2

Having a list of design possibilities, the student now has to identify which one is the most promising and feasible. This will involve some tough-minded thinking, ranging from: “This is a great idea and I’d really like to design and make it but it’s just too difficult” to “This is an OK idea and I know I can design and make it but it doesn’t really inspire me”. Whatever a student chooses it is important that it is challenging enough to be inspiring and at the same time feasible enough to be realistic. The next step involves developing and refining the chosen idea. One way to do this is for students to use the design decision pentagon (Barlex 2007) to organise their thinking (see Figure 2). The conceptual decision has already been made in choosing the sort of item they want to design and make but there are still lots of other decisions to take. These are:

- Technical decisions relating to the way the item will work – students might identify three possibilities and explore which is the best.
- Aesthetic decisions relating to the look and feel of the item – students will need to think about what might appeal to the user; what emotions it might evoke, how will it make the user feel.
- Constructional decisions – students will need to think about the different parts that make up the item, how will each part be made and how will they be assembled into the whole.
- Marketing decisions – students will already have decided on the user, but they will need to tease out their likely preferences

Note it is possible that during the development and refining phase the student realises that the design idea is not as feasible as first thought. All is not lost. The student can revisit the decisions that led to the choice of the design idea to take forward and make a different choice. But such revisiting is time consuming. There is limited time available for the contextual challenge, Awarding Organisations recommending that candidates should spend between 30 and 40 hours on the task. And this can be de-motivating so teacher support and guidance will be more necessary than usual here. At this stage it will be important to develop a performance specification to ensure that the design decisions made will meet the requirements. The students' design ideas are now becoming much more defined and they need to consider how they will make the design. Modelling various parts before actual making will probably be important. Students can model appearance in a number of ways: 2D sketching and annotating, 3D modelling with easy to work materials, and on screen using CAD. Students can model structural and mechanical function using construction kits and CAD. Students can model electrical, electronic and programmable function using breadboards and CAD. Once students have a useful set of models which allows them to draw up a clear set of plans they can start making. In some cases, it will be possible to make some parts whilst still modelling others.

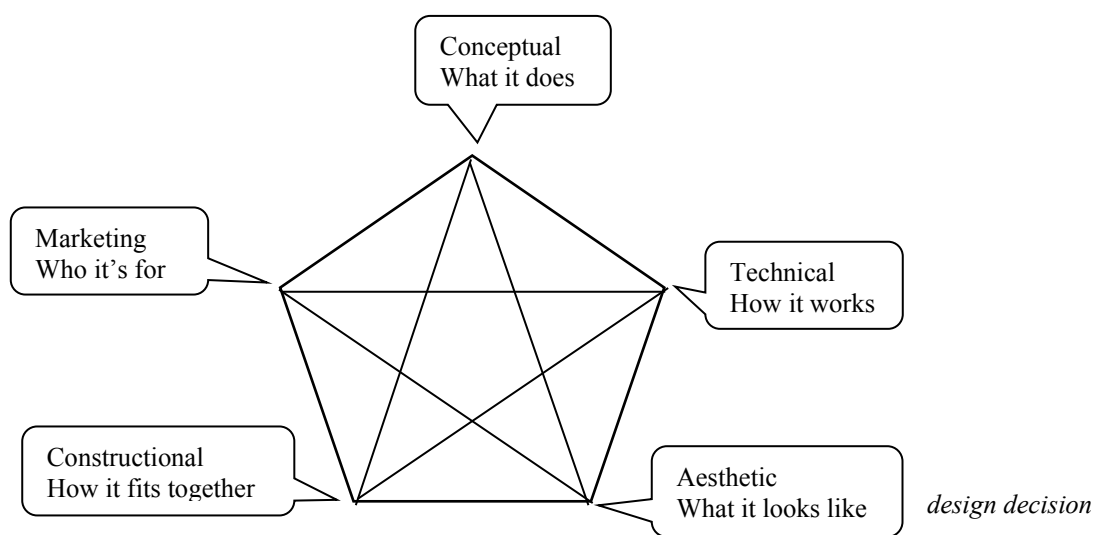


Figure 2. The pentagon

### Concerning phase 3

Once the item is completed it is time for evaluation. This should be carried out from a variety of perspectives asking the following questions:

- Did it do what it was supposed to do? This is an evaluation against the performance specification.
- Was it well made? This can be discerned by visual inspection.
- Will it last? This can be discerned by treating the item robustly for its context and seeing how well it stands up to the treatment.
- Was it easy to use? This can be discerned by taking or observing a user trip.
- Did it delight the user? This can be discerned by talking to the user.

And of course, it is important that the answers to the questions are recorded and used to generate an evaluation that highlights both the strengths and weakness in the response to the contextual challenge.

To meet AO requirements with regard to showing evidence candidates record their progress through the three phases in real time by means of a portfolio and this, along with the artefact produced, is scrutinised by teachers and moderators to provide evidence of attainment.

### PART 3 PREPARING LEARNERS FOR THE CONTEXTUAL CHALLENGE

If students have little or no experience of exploring a context and identifying for themselves worthwhile designing and making tasks in response to the needs and wants embedded in that context then there is little doubt that they will struggle to be successful in the contextual challenge. Hence teachers will need to prepare them for such a challenge so that they can tackle it with confidence. Responding to a contextual challenge cannot be ‘taught from the front’; it is only by engaging pupils in open design tasks that they will acquire the necessary knowledge, understanding and skills. To discover what teachers were might be doing to prepare the authors set up a very short questionnaire on SurveyMonkey and broadcast its presence through social media. The questions in the survey were as follows:

#### Questions

1. What changes have you made to your KS3 D&T curriculum to prepare pupils for the new D&T GCSE? [Please tick all that apply]
  - I've included more mixed materials projects
  - I've included more systems and control
  - I've introduced a greater emphasis on designing
  - The designing and making tasks have been made more open
  - There is a greater emphasis on the impact of technology on society
  - I have made no changes
  - Other – please give details
2. What changes have you made to your KS4 D&T curriculum to prepare pupils for the new contextual challenge NEA? [Please tick all that apply]
  - The designing and making tasks have been made more open
  - I've introduced sessions focussed on exploring contexts
  - I have made no changes
  - Other – please give details

42 teachers responded to each question. The results for Q1 are shown in Figure 3. Under the heading of 'Other', the responses provided for Q1 are shown in Table 1. The results for Q2 are shown in Figure 4. Under the heading of 'Other', the responses provided for Q2 are shown in Table 2.

What changes have you made to your KS3 D&T curriculum to prepare pupils for the new D&T GCSE? [Please tick all that apply]

Answered: 42 Skipped: 0

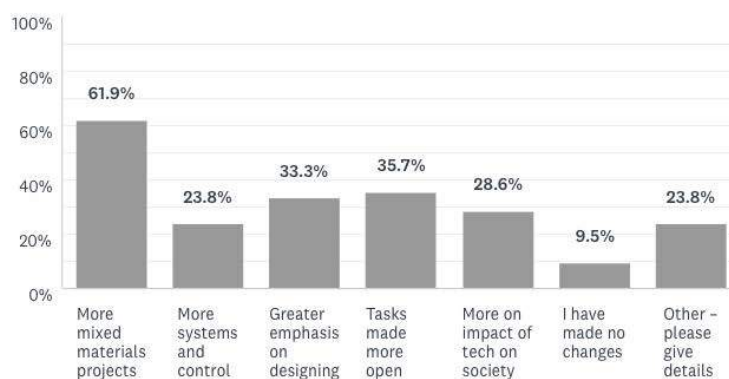


Figure 3. Responses to question 1

Table 1. 'Other' responses to question 1

More emphasis given to focused marking in particular projects. For example one project will focus on designing and evaluating and another focuses on planning and making. Some theory ideas have also been brought forwards due to time constraints at KS4 and to reinforce ideas that are more tricky particularly material properties. More maths has been included in some projects and made more obvious to students. We have also removed the carousel so the group has the same teacher all year.

More focus on coverage. Start covering simple D&T theory in the early year. The amount to get through in 2 years (years 10

<i>&amp; 11) means you have to start teaching lower down the school.</i>
<i>Removed carousels - one teacher for all disciplines</i>
<i>Changes have been made due to budget cuts - not curriculum change. less making, I can't afford materials and machines are breaking and not being replaced.</i>
<i>My sow (carousel) is now loads of mini projects covering a wide range of outcomes- theory lessons are also interactive with a practical element- homeworks assignments are evidencing how students use their outcomes through photo stories and story boards.</i>
<i>Home learning tasks have included more theoretical elements - we'll revise our projects at the end of this year.</i>
<i>Bigger focus on client.</i>
<i>I don't have a KS3 I teach in a UTC.</i>
<i>Struggling to make the changes necessary with an inexperienced department. Sticking with old fashioned design, make, evaluate ks3 projects. There is then an upskill in year 9 and 10 so they're ready for year 11.</i>

## What changes have you made to your KS4 D&T curriculum to prepare pupils for the new contextual challenge NEA? [Please tick all that apply]

Answered: 42 Skipped: 0

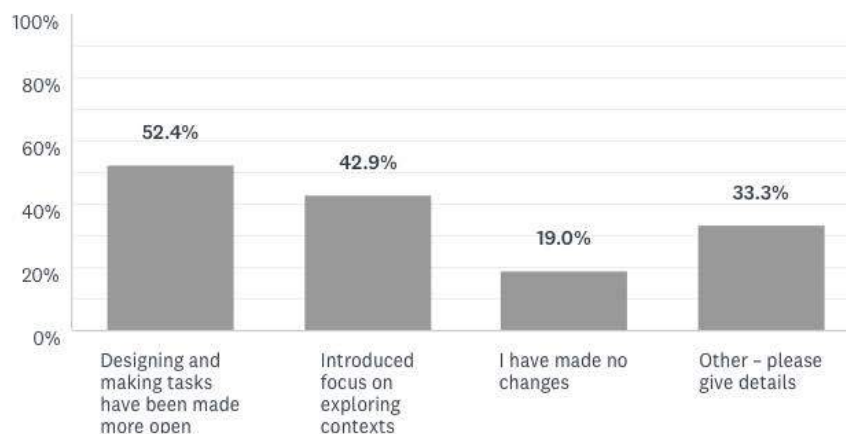


Figure 4. Responses to question 2

Table 2. 'Other' responses to question 2

<i>Topics are more clearly defined and students are encouraged to work to stricter time plans. Elements of the NEA eg researching, have been included in assessments with a mock NEA introduced in year 10 this week (early March). More emphasis has been made of the knowledge base required.</i>
<i>My design tasks at GSCE have always been open. I rarely restrict students to a particular project. A range of projects creates a stimulus for the group, a collective problem solving focus and generates different outcomes.</i>
<i>Completely revamped the delivery of theory. Will tackle the NEA when we are closer to the release date and time.</i>
<i>Focussed yr10 on core theory</i>
<i>Small focused tasks and recorded range of skills and materials and lots of theory</i>
<i>More small ppt's.</i>
<i>A mock NEA with year 10's. Constant feedback through google classroom</i>
<i>More small theory based makes to make the content less dry</i>
<i>Have done a lesson giving them a myriad of contexts and then asked them to research possible design opportunities / different briefs.</i>
<i>Spent more time on theory than I would usually do early on in a course to ensure they get all the time needed when the NEA kicks in. Was in danger of losing them at one point... Became too theory led. Quickly reverted back to designing exercises and skills lesson inputs. I have not got the balance right yet re the course (AQA) ,. 1st year... Suppose it's to be expected. Little support re NEA etc from exam board.</i>
<i>Add more theory component that covers core and in-depth of 2 materials. Have attempted to use maths activities from exemplars across exam boards. We also test theory knowledge weekly</i>

<i>Shorter design and make tasks to cover different core materials.</i>
<i>Focus practical tasks on processes and materials</i>
<i>More focus on theory within year 10. Only short practicals due to feeling there's less time for NEA</i>
<i>I've tried to focus on areas of weakness/no links will be made in, if there isn't a 'pointed out' element to it. Each small term is spent on 1 area of focus - t4 is currently mechanisms/cams/levers/gears etc</i>

Whilst this is a very small survey of self-reporting and self-selected respondents, meaning that the results are in no sense statistically valid, several interesting features emerge.

In relation to the KS3 responses, a number of things particularly stand out for us:

- We find it encouraging that the majority of respondents have introduced more mixed material projects in the curriculum; this may seem unremarkable at first sight, but, given the history of d&t in England (Atkinson, 2017), is actually a huge change in direction.
- The smaller increases in design focus, open-endedness and technology in society show movement in the direction required to prepare students for the increased profile of these elements in the new GCSE. Although the numbers look low here, it is possible that these features were already significant in the curricula of those who didn't select these items.
- The same could be argued about the relatively low numbers introducing more systems and control; however, given that we know that the ability to support electronics in d&t at both KS3 and 4 is narrowly spread and fragile, this seems to us to be an area that needs focussed support given the demands of this area of the new GCSE.
- We find it interesting that around a tenth of schools have made no changes to their KS3 teaching in preparation for the new GCSE. We can't tell whether this is because their courses were already well designed in this respect or whether other pressures have prevented this preparation being put in place.
- Arrangements for KS3 d&t teaching that are based on carousels have been criticised in the past (Steege & Davies 2005) but have remained popular largely for practical organisational rather than educational reasons. We wonder whether the schools indicating that they have moved away from a carousel arrangement are the beginning of a larger trend. We think this merits monitoring.
- There is indication in the responses that d&t departments are taking seriously the idea of seeing their curriculum as a 5-year plan from y7 to GCSE

The main and unsurprising message from the KS4 responses is that there is a significant increase in the emphasis on more open tasks and teaching about how to explore contexts.

## **PART 4 OPPORTUNITIES FOR DESIGN FOR GOOD**

Emily Pilloton (2009) argues that designers should make the distinction between 'good design' and 'design for good'. To quote Allan Chochovin writing in the foreword, when you move from good design to design for good 'the design conversation moves from form, function, beauty and ergonomics to accessibility, affordability, sustainability and social worth.' Allan is scathingly critical of much design activity, 'Perhaps the wholesale poisoning of every natural system through industrialisation are "unintended" consequences, but there's a cruel irony in designers running around, busily creating more and more garbage for our great grandchildren to dig up, breath, and ingest, all the while calling themselves "problem solvers"'. Emily's book features more than 100 contemporary design products and systems including safer baby bottles, a waterless washing machine, low-cost prosthetics for landmine victims, Braille-based building blocks for blind children, wheelchairs for rugged conditions, sugarcane charcoal, and a universal composting system.

These and all the other items described in the book make excellent case studies for D&T students on the theme of 'design for good'. Barlex (2017a) has explored how a 'design for good' approach might play out in the contextual challenge. This led to comments from members of the ITE community (Barlex 2017b) which were positive but warned that design for good could not be seen as a forgone conclusion of the contextual challenge given that 'old habits die hard' and many teachers would be tempted to adopt a minimal change approach to dealing with the new assessments requirements.

## **PART 5 POSSIBLE RESEARCH ACTIVITIES TO MONITOR THE PROGRESS OF THE CONTEXTUAL CHALLENGE**

Several possibilities of research that will monitor the progress of the contextual challenge spring to mind. In the academic year immediately after awarding qualifications to the first cohort to take the new GCSE (i.e. 2019-20) each of the Awarding Organisations should make available in the public domain a selection of anonymised portfolios (across the range of low grades to high grades) that researchers could use as the basis for a commentary on the way students have tackled the challenge and teachers could use for professional development. This could become an annual event so that the community of practice can begin to identify trends in the way the students are tackling the challenge.

Researchers, working with teachers could monitor the way that students are tackling the challenge as they tackle the challenge. This would need to be done in ways that neither impede students' progress nor give them unfair advantage, but it would give insight into the problems students face and how they overcome them

It would be interesting to investigate and identify elements of the design & technology the curriculum, both pedagogy and content, that influence students' ability to tackle the contextual challenge.

It would be interesting to compare the contextual challenges offered by the Awarding Organisation along with any professional development support they provide for teachers with a view to identifying the drivers that are influencing the nature of the contextual challenges made available to students.

### **SUMMARY**

This paper has described the nature of the contextual challenge and its role in assessing the school subject design & technology in England in the context of a similar Non Examined Assessment (NEA) in computer science being removed by Ofqual (the non-ministerial government department that regulates qualifications, exams and tests in England). It has described a three phase approach to tackling the contextual challenge and reported the results of a short, small scale questionnaire in which teachers were asked to describe the changes they had made to their d&t curriculum in preparing pupils for the contextual challenge. It has discussed the possibility of introducing a design for good approach to the contextual challenge and finally made suggestions of possible research activities to monitor the progress of the contextual challenge.

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# Drawings to depict or drawings to explain: A whole-school analysis of children's drawings of bridges

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This paper discusses a set of data comprising student's drawings gathered during a whole-school technology unit. The teachers and senior management team at the school aimed to gain a snap shot of students' design drawings skills. From the analysis of student work, they hoped to develop a plan of how to progress the students' drawing skills to the next level. The contextual focus of the technology unit was bridges, and the students studied a number of examples in their local area. A designer and structural engineer were invited to speak to the senior students about materials and structural properties of the town bridges, whilst the younger students considered the function of a bridge and enjoyed stories in which a bridge played a major role. The later part of the unit involved the students designing a bridge, and some classes created models. The data set used for this paper includes 54 drawings drawn from the original random sample of 80 senior students drawings (Years 5-6), 70 middle school drawings (Years 3-4) and 50 junior students (Years 0 – 2). The junior students completed drawings prior to the beginning of the unit, as well as towards the end of the unit. The middle school and senior students experimented with a series of views and techniques prior to developing their final bridge design. Whilst these examples show an extensive range of drawing capabilities across the school, they also show the impact that technological knowledge can have on the creativity and design ideas of primary aged students. This emphasises the notion that knowledge is key to effective technological development. To quote Bruce (2011, p. 78), "Creativity doesn't come from nowhere. It feeds off our experiences. It depends on experience of life in order for creative ideas to develop".

*Key Words: Design, drawing, Technology education, Primary, Creativity.*

## 1. INTRODUCTION

A chance meeting with a colleague at a local school resulted in the delivery of a school wide set of 54 primary aged students' drawings to my office. The staff had gathered these during a whole-school technology unit in which they aimed to gain a snap shot of the context-specific knowledge achieved by their students during the unit, an indication of students' drawings capabilities across the school, and, as a result of their analysis, ideas of how to progress students' design drawing skills. The data gathered for each class comprised of low, medium and high skill development as judged by individual class teachers. Teachers representing each syndicate met to moderate the assessments, and write a final report that summarised their findings. The reports and the recommendations were presented to the school's senior management team for further consideration.

The school from which this data originated was multicultural, with a role of 600, and a decile rating of five i.e. a middle range measure of the socio-economic status of the immediate community (Ministry of Education, n.d). The contextual focus of the technology unit was bridges, and although this is not a personal favourite of mine, (as it generally slips into the category of 'making lunch boxes for Martians' i.e. making things you know very little about) the data set that was undoubtedly worthy of further analysis. The junior classes' data included before and after drawings, and these showed a wide range of technical skill and varying levels of technological understanding. The middle and senior school students experimented with sketching three-dimensional views, exploded views, top and side views, and these revealed a wide range of technical skill. The students' understanding of materials, structure and the complex functioning of a bridge were clearly advanced through the unit. To assist with the examination of this work, an artist and lecturer at the Faculty of Education, University of Waikato, Donn Ratana, worked alongside me to provide the following overview.

## 2. EXAMPLE 1: JUNIOR SCHOOL (5-6 YEAR OLD STUDENTS)

### 2.1. Unit description

The teacher planning for the junior students described a focus on building students' knowledge of the look and function of bridges. There was no evidence to suggest specific teaching aimed at progressing students design drawing skills. The teaching sequence began by sharing ideas about the definition of technology and was followed with students drawing an unassisted image of a bridge (a before view). The teacher annotated each of these and prompted the students' descriptions with a number of questions, for example, tell me about your bridge, what is it made of, what is it for and is it safe? She read stories that featured a bridge, and discussed bridges that were famous and those that were local. The students were then encouraged to create a model of a bridge that was strong enough to hold a small toy car. An extensive period of experimentation and discussion followed. The final task was to draw a bridge that was strong. As before, the teacher annotated each one, prompting the students with a single request - "Tell me about your bridge".

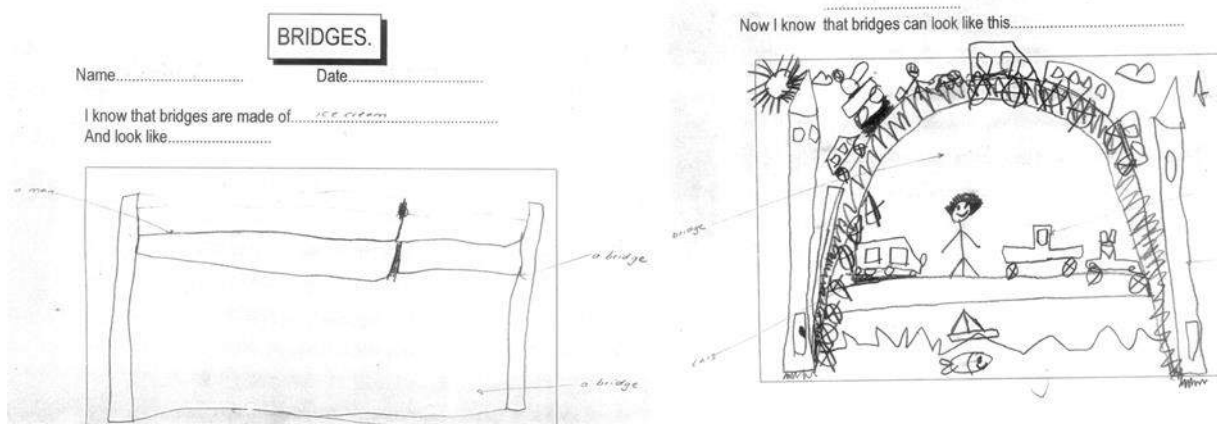


Figure 1: A 'before' and 'after' drawing of a Junior School student's bridge (1a [left] and 1b [right])

#### 2.1.1. Drawing skills demonstrated in 'before' views

Looking across the 17 examples of 'before' drawings for this age group, there was, unsurprisingly, a huge variation in their technical skill. Drawings ranged from simple shapes with no detail, through those with rudimentary structural and functional detail. The images consisted of contour drawings or outlines, five examples using a rectilinear style (or straight lines) as in Figure 1a, and 12 showing elements of a curvilinear style (or curved lines) as in Figure 1b. One six-year-old student used an X-ray style to depict railings on his bridge and another drew an exhaust at the rear of a car that showed movement and direction over the bridge.

#### 2.1.2. Technological knowledge revealed in 'before' views

Of the 17 'before' examples from the junior students, nine students referred to the purpose of a bridge, and explained to their teacher that people, animals and cars were able to cross a river. Three students understood the general purpose of a bridge, but no mention was made of who or what would be using the bridge. The students appeared to have a good grasp of the construction materials required to build a bridge. Seven students referred to wood, four to bricks and five others mentioned materials such as metal, concrete, and cement.

The annotations added to the drawings by the teacher referred only once to the specific structures or components of a bridge. One student said 'side pieces' would be used for people to hold on to. This is typical of young students whose context-specific knowledge is usually limited, who are not confident users of the language associated with a new topic and who resort to the use of approximations to express their ideas (Milne, 2015).

#### 2.1.3. Technical skills demonstrated in 'after' views

The 'after' views showing the students' interpretation of 'strong' bridge, showed considerably more detail. The second example in Figure 1 is typical. Whilst the drawings were still contour drawings, four students included shading in their drawing and four others 'restated' drawn lines, i.e. repeatedly drew over lines which usually suggests strength or a solid structure. All 17 drawings showed both straight and curved lines, and whilst these



were two dimensional, there was an increasing natural realism to the images. The drawings were recognisable, there were attempts to show proportion, and there was increased clarity around the structure, position and function of the bridge (see Figure 1b). On a scale of low to high, Figure 1b was assessed by the teachers as being in a medium range of ability for 5 – 6 year old students.

#### *2.1.4. Technological knowledge revealed in 'after' views*

The drawings show that students' were aware of the specific nature of a bridge – its structure and its shape. Twelve of the 17 students drew an arched bridge, four drew a suspension bridge (see Fig 2), one drew a beam bridge and one drew a cantilever bridge. Six of the eight students in one class showed a variety of vehicles and pedestrians using the bridge and each of these had towers on either side (see Fig 1). The students were all conversant with materials suitable for creating a strong bridge and of the 17 students, 12 explained that their bridge would be made out of concrete, steel, wood or metal. Descriptive terms were peppered through these 'after' views and included terms such as an approach, a deck, piers, foundations, cables or an abutment. Safety for the pedestrians and vehicles using the bridge was also mentioned, and seven students referred to the inclusion of safety rails. To quote my colleague, Donn Ratana, there was “a lot more story” in these drawings (D. Ratana, personal communication, 12 April, 2018) . The influence of new context-specific knowledge since the students completed their first drawings was clearly evident despite the absence of teaching specifically designed to progress their design drawing skills.

### **3. EXAMPLE 2: MIDDLE SCHOOL (7-9 YEAR OLD STUDENTS)**

#### ***3.1. Unit description***

The teachers in the middle and senior school based their teaching on a shared plan that guided students through a detailed investigation of local bridges, bridge users, construction materials, and the positioning of a bridge over a waterway. Under the guidance of a teacher with a background in design and graphics, there was also focus on developing the students design drawings skills.

A designer and a structural engineer involved in the construction of an inner-city bridge were invited to speak to the students about their experiences. Vocabulary that described the different types of bridges was introduced, along with the structures that would generally be included in a bridge design. Issues of safety, aesthetics, and maintenance were also included. It is unclear at what point the students were introduced to their next task of building a model of a bridge that could hold a 500- gram weight. Knowledge of this prior to the presenters visit would have provided a valuable connection between the practice of the engineer and their own design task – a link between the real world and the classroom.

The final task in the unit was to create a drawing of their model bridge. An example is shown in Figure 2. The students were encouraged to include a range of technical drawing perspectives and to include materials, measurements and labels showing the individual components of their bridge design. Teacher notes suggest that the students were encouraged to use a ruler. The example provided in Figure 2 was assessed by the teachers as being in a medium range of ability for the Year 3 - 4 students.

#### *3.1.1. Drawing skills demonstrated in students' model bridge designs*

Each of the ten students in this set of data were able to present a realistic, view specific, two-dimensional drawing of their bridge design. They used contour or line drawings, with three students included shading, two of which indicated a strong or solid feature in their design. Two of the ten students were able to draw an accurately angled three-dimensional view; two others attempted this but with limited success (See Fig. 2). Depending on the aspect that was chosen, half of the students were able to show an exploded view, and two others made an attempt but the image was unclear. The cross-sectional views were attempted by all students; two were very clear, and others more difficult to interpret. The birds-eye views proved most successful with four students able to present visually realistic images, and three others with images that were recognisable but with minimal detail. All students used single colour schemes and each drawing showed a developing awareness of proportion.

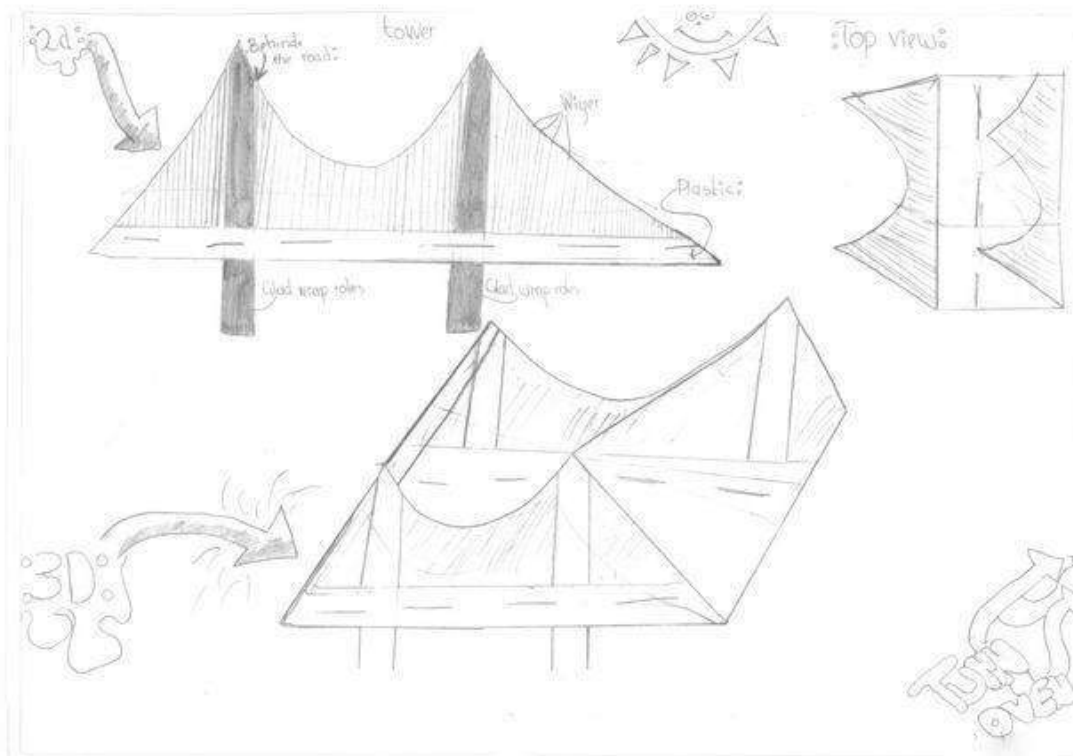


Figure 2: A Middle School students' drawing of a model bridge

### 3.1.2. Technological knowledge revealed in students' model bridge designs

The Middle School students' drawing was a retrospective drawing of their model. All 10 students were able to identify the materials they required to build the model, five students listed between five and seven materials in an information box at the side of their drawing, and five students labelled the materials directly onto their drawing. Two students included key measurements in their design and three named several of the structures, for example cables, a deck or a post. The purpose of the drawings seemed unclear as they tended to be memory drawings rather than those that had the potential to explain a construction process – these were drawings that, to quote Rogers and Wallace, “depict rather than explain” (2000). This may have accounted for the absence of information regarding how different materials in the models were connected. Aside from one student's drawing which included an exploded view of cellotape fastening pieces of material together, there was no reference to assembly techniques used during their model making.

## 4. EXAMPLE 3: SENIOR SCHOOL (10-12 YEAR OLD STUDENTS)

### 4.1. Unit description

The senior students were guided through a unit similar to the Middle School syndicate, with each teacher modifying the content and the sequence of lessons to suit their class. The task for the students' drawing and construction was a little more complex. These students were asked to design and build a 50cm long bridge that spanned a 30cm divide and successfully supported a 1kg weight at its centre. The students carried out a materials analysis task in which they considered fifteen materials found in their classroom that would be available for construction purposes. These included items such as kebab sticks, plastic bags, foam, string, mesh, sponge and others. The students were asked to rate each material from one to ten, according to properties such as elasticity, rigidity, flexibility, malleability, strength and torsion. They also discussed the development of bridge construction over the centuries, and how these structures affected the towns and cities that they served.

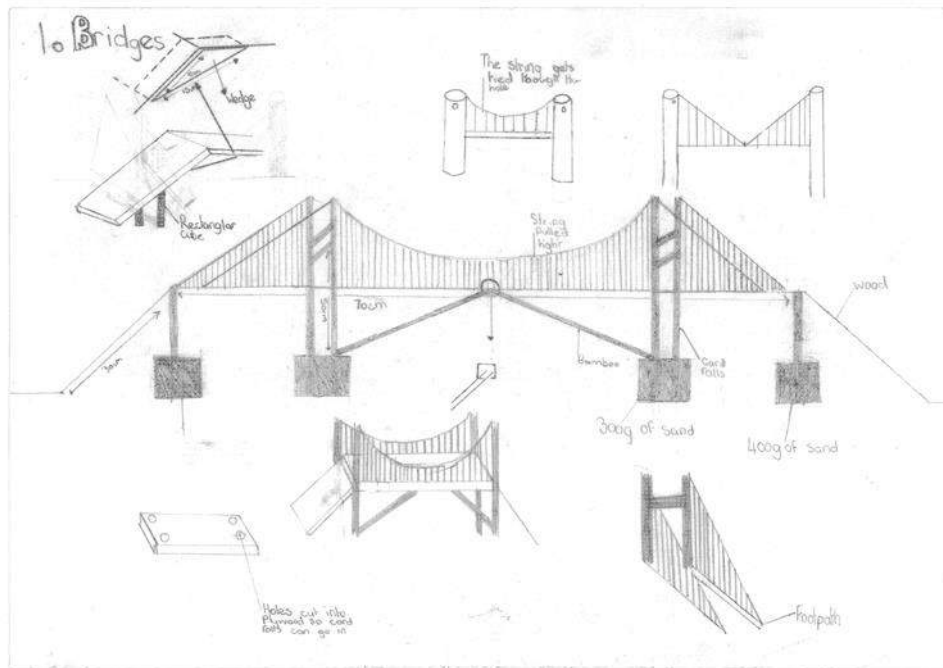


Figure 3: A senior school students' bridge drawing showing multiple views

#### 4.1.1. Drawing skills demonstrated in students' model bridge designs

In this set of 27 design drawings there was a range of techniques similar to those found in the Middle School students' data. There were two and three-dimensional drawings, birds-eye views, and cross-sectional views (See Fig. 3). The teachers' planning indicated that these techniques had been modelled by an expert teacher, the students had practiced them, and the teachers had encouraged them to include them in their final drawings. A noticeable difference in this set of data was the increased skill level. These drawings showed more detail, and many students included annotations describing how materials were joined as well as details of construction. The students used contour drawings, but there was an increased use of rendering and shading which enhanced the realism of their drawings. One class, whose teacher was the designated design and graphics 'expert' was particularly successful putting this technique into practice. All but one student from this class, used rendering or shading to show a solid section in their structure and/or the effect of light and shadow on their drawing. Of the whole group, ten of the 27 student drawings from the senior school data set, used this technique in their drawing.

Half of the senior school students were able to draw a three-dimension image of their model bridge (See Figs 3 and 4). All students were able to create a simple birds-eye view of their structure, fifteen students included measurements of materials, with three students attempting to create scale drawings. Of the fifteen detailed views that were included in this set, six provided valuable information about the construction of the model whereas others added little to the information already provided in the drawings. The annotation alongside the detailed view in Figure 4 explains, "quite thick cardboard slides through the gap of the toilet roll and gets hot glued to stay steady". Using the same assessment categories as previously, both examples were scored in the high range with Figure 4 seen as advanced for this age group.

#### 4.1.2. Technological knowledge revealed in students' model bridge designs

The Senior School students' drawing was a design of a model they intended to build. All but two students listed the materials they planned to use and these were labelled directly onto their drawings. The materials analysis carried out prior to the design phase appeared to inform the students' decision making – materials were chosen for their strength and stability. However, the intended function of the bridge seemed uncertain. One student selected concrete and steel for the construction of his bridge, and stated it was for bikes and cars. Several others said the bridge was for people, cars and bikes and included a road and/or a bike lane. This aside, the advance of technological knowledge and the finer detail describing the structure of a bridge was apparent through the majority of these drawings. A third of the students included labels for the key parts of their bridge, for example

bracing and bolts (see Fig. 4), an anchor (or underwater foundation), an arch, access ramp, support beams, and railings. It is unknown which context-specific understandings the students had prior to the beginning of this unit, however their ability to accurately use the terms that were introduced during the unit, confirms their ability to apply that knowledge to a practical outcome.

A marked difference through this data was the inclusion of construction information and details of how materials would be connected. Ten students included details of how their bridge would be built and eleven students described how bridge components would be joined. For example in Figure 4 the student notes she would need to “string ties around the wire” which would then be “hot glued to the bottom of the cardboard to stay tight” (Lulu, n.d). Another student explains: “The fence has a bendy wire top and the bits coming down will be tied to the wire and lashed to the bamboo” (Katie, n.d). It is not known whether these students were prompted to include these details or whether, because of the nature of the task and the students’ understanding of the purpose of a design drawing, that they included these of their own volition.

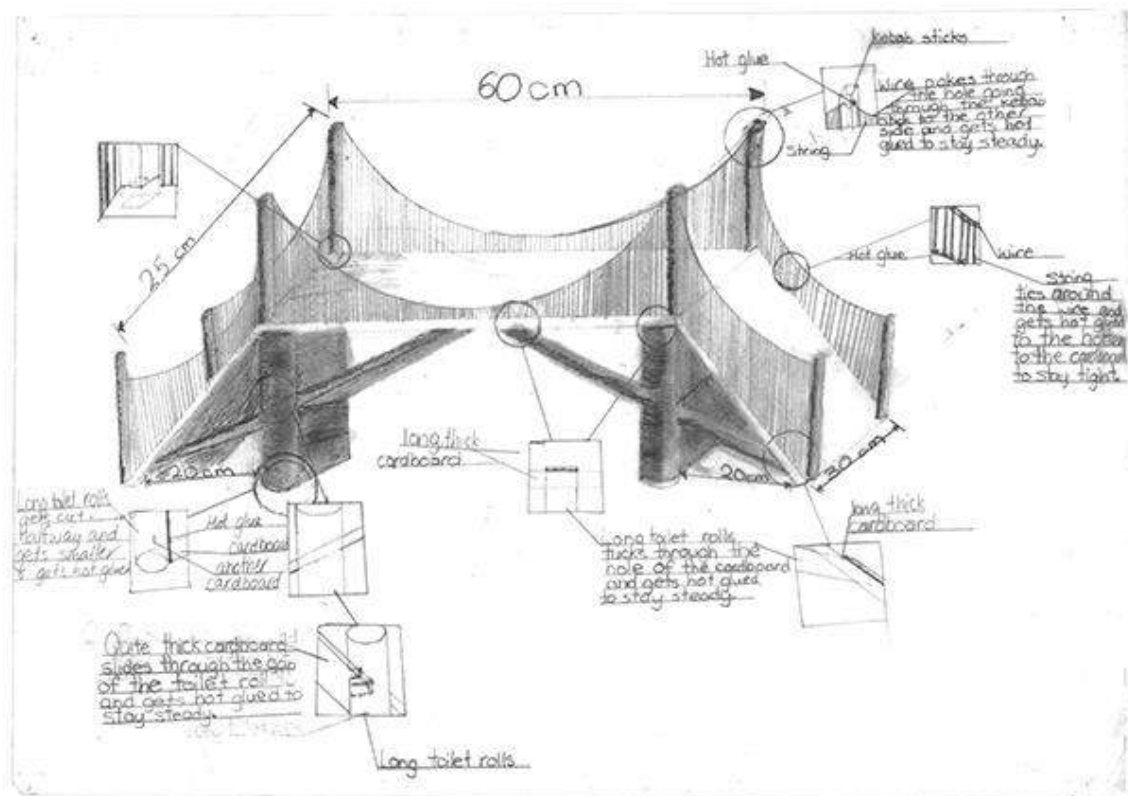


Figure 4: A senior school students’ annotated drawing of a bridge design

## 5. DISCUSSION

This paper describes the reanalysis of secondary data. There are gaps in the background information that was available, but the examples of students' drawings from across the school, and documents describing teacher planning, together provide the basis for some worthwhile discussion.

What do we know? There are three key ideas, which emerge from this data: firstly, that students' drawing skills are influenced by their context specific knowledge and by exposure to techniques that enable them to effectively think about and share the detail of their design ideas. The complete data set showed a predictable progression of students' drawing skills across the class levels, with the junior students creating 'after' drawings which showed enhanced detail of the features and function of a bridge, and the middle and senior school students beginning to construct drawings that also communicated information. Secondly, students need to be clear about the purpose and function of their drawings, and closely aligned with this, is the formation of a well-defined technological task or problem upon which students' design ideas can be focussed.

At the beginning of this paper, I quoted Bruce (2011, p.78), who argued that "Creativity doesn't come from nowhere. It feeds off our experiences. It depends on experience of life in order for creative ideas to develop". Teacher knowledge of how to nurture a creative learning environment in which students feel emotionally safe, willing to take risk, make mistakes and generally to break the rules of engagement (Bruce, 2011) is the cornerstone upon which creative design ideas depend. Left alone, young students are likely to experiment with materials in order to find a solution to their problem rather than sketch their ideas. Whilst this may appear to hamper their design thinking, research suggests that the most important element that impacts on the breadth of their ideas, is the experience and exposure they have to the relevant field of inquiry (Carter, 2004). This is demonstrated in the junior students' drawings where in Figure 1 the simple rectilinear style drawing of a 'before' view, burgeons into the curves and lines of a busy city bridge in the 'after view', complete with cars, trucks, vans and people, with towers at both ends and a magnificent arch spanning the river.

Hope (2017) describes students drawings as being a "discussion document" (p. 84) that can be shared with others, critiqued and modified. The middle and senior students' drawings demonstrate significant growth in their content knowledge of bridge structure, materials and function, as well as demonstrating some impressive technical drawing techniques. However the understandings these students had of the purpose of their drawings appeared tenuous, and the focus of the technological outcome was uncertain. Undoubtedly the students content knowledge and design ideas flourished, but the absence of a clearly defined set of criteria for the design project being undertaken, impacted on the notion of connectedness and continuity illustrated by Moreland and Cowie (2011).

Egan (1995) and Rogers and Wallace (2000) have also emphasised the need for students to understand the difference between drawings that explain, as in a plan, and drawings that depict, as in a piece of art work. Where students are able to conceptualise the difference between the two, the task of creating a design drawing is more likely to merge with the process of technological development and give it greater meaning and purpose (Milne, 2015). It is unclear how the purpose or function of these drawings were communicated to the students during the bridges unit. It seems, that in maintaining a clear link to the real world, where the purpose of cross-sectional and exploded views are to communicate specific detail to a manufacturer, for example, real purpose also needs to be provided in the classroom environment and this was not evident through the data. The design tasks presented to each group of students varied. The juniors were simply to create a bridge that was strong, whilst the middle and senior students were to design a bridge that would hold a specific weight. Although these tasks gave some direction to the students, there appeared to be a disconnect between developing context specific knowledge and skills, thinking about a design solution for a real purpose, and creating a design solution.

In conclusion, it is fair to say the original goal of gaining a snapshot of the design drawing capabilities of the students across the school was clearly realised. However, bearing in mind the intent of the technology curriculum, the relevance of the students' technical skills lies with the intended purpose of the drawings and the technological task being carried out.

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# Effects of Convergent and Divergent Feedback on Creative Thinking During Children's Design Processes

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This paper explores patterns in the feedback preceding instances of design fixation in children (age 9 to 11) carrying out a co-design project. Our goal is to find ways to improve the early mastering of their divergent (DT) and convergent thinking (CT) skills, which in turn will help the children to develop their creative abilities. Previous research has shown that children who participate in a design process experience difficulty in adjusting, changing and elaborating previously selected design ideas. This dynamic is referred to as design fixation. In the case study presented here we analysed the feedback preceding the fixation moments of the children, using Eris's question-driven design model. We found that most of the feedback was convergent in nature and, additionally, that feedback that could be considered divergent did, for the most part, not spark any DT processes within the design teams. We presume that the expectations and assumptions that were implicitly present in the feedback has negatively influenced the possibility of any new DT processes. Based on the conclusions of this research we will explore new methods and tools stimulating divergent feedback in order to prevent and overcome design fixation during the children's design process.

*Key Words: Divergent thinking, Convergent thinking, Design education, Feedback, Design fixation.*

## 1. INTRODUCTION

In this paper, we describe an explorative case study in which we observed the development of the design ideas of a group of primary school children (age 9 to 11) carrying out a design project. In the first analysis round of this explorative case study Schut, Van Doorn & Klapwijk found that the children experienced difficulty in adjusting and elaborating previously selected design ideas, which stagnated the development of their design ideas; the children experienced design fixation at several moments during their design process (Schut, Doorn, Klapwijk, & Design, 2017). These fixation moments were observed through the response behaviour of the children during their conversations with the problem owner (the client), facilitators and peers. This response behaviour, indicating fixation moments, could ultimately be grouped into four categories: 'band-aids', 'already-in-there', 'question-not-relevant' and 'it's-not-possible'. Building on this, we will focus in this paper on identifying the type of feedback that the children received preceding those already identified fixation moments. The goal is to get a better understanding of the type of feedback that preceded those fixation moments and uncover possible feedback patterns. It is expected that with this knowledge, new interventions can be created for future design projects in primary schools, where feedback can be shaped in ways that contribute to the development of creativity.

## 2. LITERATURE REVIEW

In recent years, more and more focus is put on children's ability to behave creatively while taking part in design subjects like Design & Technology (D&T) (Benson & Lunt, 2011). To be able to behave creatively divergent (DT) and convergent thinking (CT) skills are needed (Cropley, 2006). DT entails the generation of novelty, which is commonly thought to go hand in hand with the ability to see many possible answers and interpretations to a problem or issue. CT entails the evaluation of this novelty, which deals with coming up with, or selecting, the 'best' answer to a problem or issue. The ability to separate and alternate between the two

is considered extremely valuable when developing creative solutions (Guilford, 1967; Howard-Jones, 2002). The Creative Problem Solving (CPS) tradition shows that methods that strictly separate DT and CT modes by phasing them can benefit creative behaviour in the design process (Tassoul, 2009). As the amount of alternations of DT and CT increases, the design process becomes more sophisticated (Mioduser & Kipperman, 2002). Through this alternating process, the design ideas keep on developing. When an idea is being developed and problems arise, these problems need to get solved. This creates the need for new input in the form of ideas (DT) and this in turn leads to the selection of one of these ideas (CT) as the solution that will ultimately become part of the design idea.

Previous research has shown that it's not easy for children to develop their creativity in D&T education. This is due to various external reasons, like available teaching methods, teacher beliefs and examination requirements, and internal reasons, like the children's tendency to get fixated during their design process (Thijs, Fisser, & Hoeven van der, 2014; Nicholl & McLellan, 2008; McLellan & Nicholl, 2009; Nicholl & McLellan, 2007). Fixation during the design process was first described by Jansson and Smith, which they refer to as design fixation. They describe it as "a blind, and sometimes counterproductive, adherence to a limited set of ideas in the design process" (Jansson & Smith, 1991). Purcell and Gero (1996) also note the aspect of premature commitment to a particular problem solution: "...the designer appears trapped by the characteristics of a possible solution that has been developed or an existing precedent solution". Fixation can drive a designer to be stuck in a certain train of thought that does not produce its intended goal. Success in developing a design idea depends on abandoning this train of thought and generating alternative ones (Smith, 1995). Yet people are prone to think along the 'path-of-least-resistance' and therefore likely to form ideas from easily accessible pre-existing concepts from their memory and stick to them (Ward, 1994). Nicholl and McLellan researched the phenomenon of design fixation in secondary design and technology (D&T) students (Nicholl & McLellan, 2007; McLellan & Nicholl, 2009). They suggest that design fixation is widespread among the work of secondary D&T students.

When designing alone, or even in a team, it is easy to get lost in a specific train-of-thought due to the absence of external input. Different strategies can be used to enhance idea development and discourage fixation during the elaboration of the design. Among those are interventions that provide a form of feedback on the design: making a prototype, testing the prototype and receiving feedback from various stakeholders (Crilly, 2015). Feedback sessions, or design reviews, are a common educational practice in design disciplines at a university level to discuss the progress of a student's design project and to gather feedback (Goldschmidt, Hochman, & Dafni, 2010; Yilmaz & Daly, 2014). During these design reviews students get the opportunity to update the instructors, their peers: design students and other stakeholders, such as real or simulated clients and potential users, on the current status of their design project. In addition, questions are asked by the instructor and other stakeholders to the students to clarify aspects of the design project and to guide the design focus. This in turn can encourage the students to take convergent or divergent paths in their design process helping them with the development of their design idea. Feedback sessions while designing in an educational setting have been mostly researched in an academic setting. Here we've put this phenomenon in the context of primary education and we focus on feedback preceding instances of design fixation.

### **3. METHODOLOGY**

In this study we focus on identifying the type of feedback that the children received preceding the fixation moments that were identified during a previous analysis round of this explorative case study (Schut et al., 2017). The goal is to get a better understanding of the type of feedback that preceded those fixation moments and uncover possible feedback patterns.

The study took place at a primary school in the Netherlands, in the area of Zuid-Holland. In this study, one class of a Dutch primary school participated over a period of seven weeks in weekly design sessions of 90 to 120 minutes in March and April of 2016. The class consisted of 24 children, ranging from 9 to 11 years old. The class of children had not participated in any design project prior to this one. The class was divided into 6 teams of 4 children by the teacher, so called design teams. The design assignment of the project was made available by the HALO (sports academy), which is part of the The Hague University of Applied Sciences in the Netherlands. A problem owner from the HALO, who acted as a client towards the children, introduced the



design assignment to the children and was present during several of the design sessions to give feedback on the children’s design ideas. The design assignment was presented as follows: “design a game, lesson or sports equipment for the gymnasium of the future that enables children with different participation motives to be physically active together”. Three facilitators were present during the design sessions to facilitate the teams. When participating in the design sessions, the design teams were led through different diverging and converging stages via the different design activities. An overview of the design activities can be found in table 1. Different strategies were used during the design sessions to enhance idea development and discourage fixation. Prominent were the feedback sessions halfway in session 4 and at the end of the project in session 7. The feedback sessions were facilitated in a classroom setting in which all the design teams and the problem owner were present. Each design team took turns to present their design idea to the other design teams (their classmates) and the problem owner. After presenting, each team received feedback from their classmates and the problem owner on the status of their design idea.

*Table 1. Overview of the design sessions, including facilitation style, design activities and relation to each design phase.*

	Facilitation style	Design activity	Relation to each design phase
1	classroom facilitation	Exploring the design problem	<ul style="list-style-type: none"> <li>- introduction design assignment by the problem owner</li> <li>- experiencing different sport preferences within the class through group activities lead by the problem owner</li> <li>- timeline visualization of positive and negative physical education experiences</li> <li>- brainstorm to shed first ideas</li> </ul>
2	Separate team facilitation	Empathizing with the target group	<ul style="list-style-type: none"> <li>- constructing interview questions</li> <li>- practice interview</li> <li>- homework: do interviews with other children</li> </ul>
3	separate team facilitation	Idea generation & selection	<ul style="list-style-type: none"> <li>- discussing the interviews</li> <li>- 3 brainstorm techniques</li> <li>- categorization of all ideas</li> <li>- idea selection</li> <li>- top 4 selection</li> </ul>
4	classroom facilitation	Feedback session	<ul style="list-style-type: none"> <li>- make a small model/first prototype of 2 ideas</li> <li>- present the 2 ideas to the problem owner and classmates</li> <li>- <b>feedback from the problem owner and classmates</b></li> <li>- selection of 1 idea</li> </ul>
5	separate team facilitation	Building a prototype	<ul style="list-style-type: none"> <li>- make a building plan</li> <li>- build a prototype with provided materials</li> <li>- make a testing plan</li> </ul>
6	classroom facilitation	Testing	<ul style="list-style-type: none"> <li>- build-up for the test</li> <li>- test with other children</li> <li>- get feedback from testers</li> <li>- think of implications for design</li> </ul>
7	classroom facilitation	Feedback session	<ul style="list-style-type: none"> <li>- present design to the problem owner and classmates</li> <li>- <b>feedback from the problem owner and classmates</b></li> </ul>

### 3.1. Data collection

The data collection consisted of several different sources. The seven sessions described above were audio and video recorded and later on transcribed by two researchers. Any materials that the children produced during the sessions were photographed.

### 3.2. Analysis

Session 4 and 7, in which the feedback sessions took place, were selected for in-depth data analysis. The purpose of the analysis was to understand which type of feedback preceded the previously observed fixation moments of the design teams, therefore the data of this previous analysis (Schut, Van Doorn & Klapwijk, 2017) was used to differentiate between feedback preceding fixation and other feedback. We were particularly interested in the divergent or convergent nature of the feedback. To determine the nature of the feedback, Eris’s

question-driven design model was used as coding scheme (Eris, 2004). Eris based his model on 6 reviewed taxonomies of questions, which he adapted into his own coding scheme for the context of questions asked while designing. Although the model is intended, and therefore mostly used, to analyse question behaviour within the same design team while working on a design project (Cardoso, Badke-Schaub, & Eris, 2016; Eris, 2004), instances of its use during feedback interventions, like design reviews, are proven valuable (Cardoso, Eris, Badke-schaub, & Aurisicchio, 2014). In figure 1 Eris’s model is visualized. For the purpose of this research ‘Compliment’ and ‘Critique’ were added to the framework, so a combination of deductive and open coding was applied by use of Atlas.ti.

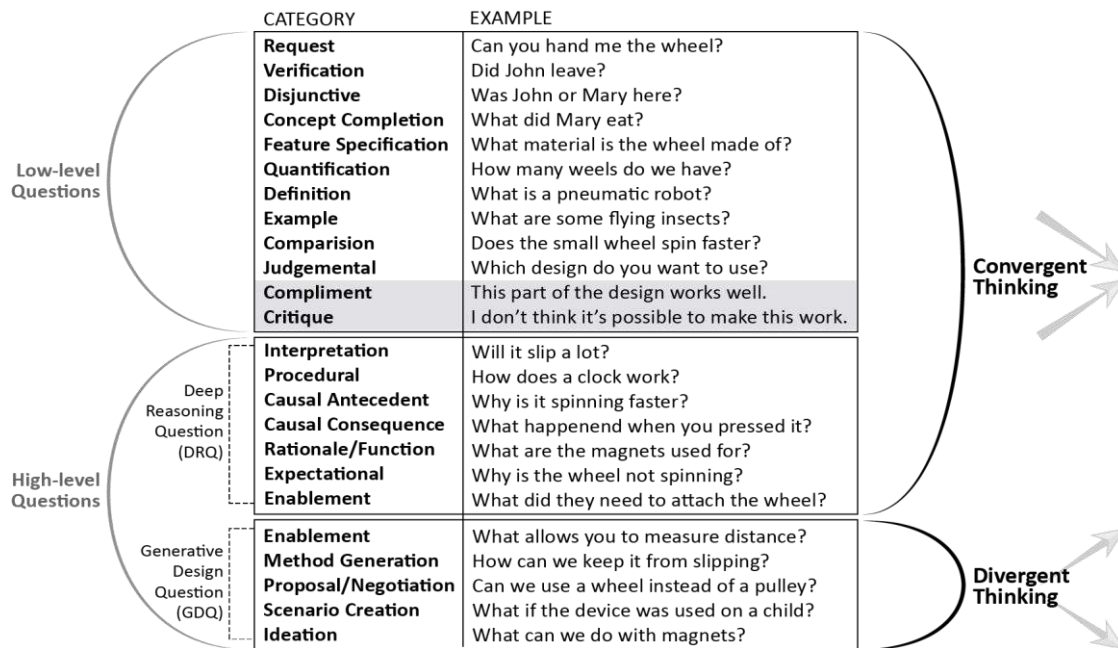


Figure 1. Eris’s Question Driven Design Model. For the purpose of this research ‘Compliment’ and ‘Critique’ were added to the framework.

## 4. RESULTS

Overall *convergent* feedback was most prominent preceding the fixation moments of the design teams. The classmates of the design teams took a leading role in giving this type of feedback, although there were some instances in which they shared *divergent* feedback with the design teams. In general, most of the divergent feedback that preceded the fixation moments of the design teams was given by the problem owner. Repeated patterns were observed in the manner in which the feedback was given to the teams, by their classmates and the problem owner preceding fixation moments. The following sections will elaborate on these observed feedback patterns through several dialogues that took place between the children and the problem owner. The children that are a part of the design team the dialogue is focused on, will be indicated as ‘child’ and, if necessary, a number. The children that are not a part of the design team the dialogue is focused on will be indicated as ‘classmate’ and, if necessary, a number. The problem owner will be indicated as such.

### 4.1. Expectations and assumptions about the design ideas

Expectations about the presented design idea appeared to be prevalent in much of the feedback that was posed by the classmates of the design teams. Through convergent feedback the classmates revealed to the design team how they expected certain mechanisms in the design idea to function incorrectly. The following ‘no handball included’-example illustrates this.

### **No handball included**

*Classmate: If you for example throw a ball during handball, then the computer can never know how fast you throw. Because he can also not...*

*Child1: But we don't offer handball.*

*Classmate: Okay. Then soccer, if you then kick the ball then you don't know how fast you will kick.*

*Problem owner: Well, the computer would be able to measure that. You can make that happen.*

*Child2: Yes, there are machines that can measure how fast it goes.*

Here the expectation of the classmate is that the computer will never be able to measure the speed of a ball thrown within the game. First the design team tries to parry the question by focussing on the sport used in the example, which they state is not part of their idea. This behaviour enables the team to ignore the question and show that their idea still 'works'. The classmate then repeats the expectation, prompting the problem owner to step in and contradict the expectation of the classmate, which is quickly embraced by the team. The first reaction of the team to feedback of the classmate was to parry it, showing little intention to evaluate the feedback and possibly using it to improve their idea. This, almost wary, behaviour could have been promoted by the classmate sharing expectations about the idea without any verification towards the team as to whether these assumptions are indeed correct.

In a few instances, classmates intertwined convergent feedback with divergent feedback. This divergent feedback consisted of either a new addition to the design idea, a small idea proposal, or a question intended to spark idea generation regarding a specific feature of the design idea. This behaviour is illustrated by the following 'scorekeeper'-example.

### **Scorekeeper**

*Classmate: Maybe it would be fun if you would also have a scorekeeper.*

*Because maybe the children will keep their own score, but you can also lie that you have 20 points while you only have 15 or something.*

*(Design team directly starts mumbling in disagreement)*

*Child 1: No that's not possible, because you have to throw your objects in a bucket and if you don't, well, then you just don't have any points.*

*Child 2: Yes, and uhm... there will be a referee that checks if there are no weird things going on and he will also count the points in the end of the game.*

*Classmate: Okay...*

The example dialogue starts with a classmate sharing a new addition to the idea of the design team: a scorekeeper. Additionally, the classmate explains that the proposal stems from the expectation that players might lie about the number of points they have collected during the game. In theory, the proposal has the potential to kick-off a new process of DT, yet here the design teams did not engage in any new DT behaviour. Instead, they listed all the reasons why the classmate's proposal would not fit their design idea. Yet similar to the previous example, the expectation of the classmate - that the players might cheat - is an assumption which again is not checked with the design team. From the reaction of the team it is clear that the possibility of cheating, which the classmate assumes to be problematic, is not viewed as a problem by the design team.

## **4.2. Proposing new additions**

Similar to the 'scorekeeper'-example, there were other instances when fixation moments of the design teams were preceded by divergent feedback. This occurred on several moments when the problem owner gave feedback to the teams. The following example dialogue showcases how one of the design teams reacts to the divergent feedback of the problem owner, who proposes a stream of new additions to the team's design idea.

### **New proposals**

*Problem owner: What might be nice is something you can see in some playgrounds.*

*That you get points if you hit something. You know?*

*Child: Yes, this game is that you can shoot and then you get points.*

*Problem owner: Yes. And that could be from two sides this way. Right?*

*Maybe the computer can control and move this, or that you move it yourself.*  
*Child: If you stand there the sticks will fall and then you can get them really fast.*  
*Problem owner: Yes, nice. Or maybe this goal can turn around and that you think of a game in which the goal moves around all the time.*  
*That will keep making the game more difficult.*  
*Child: [silence...] Maybe...*

The problem owner starts with proposing a new addition to the game. The design team reacts by stating that his proposed addition is already present in the idea. The problem owner then continues with a stream of several new additions, showcasing different directions in which his proposal could be manifested in the game. The dialogue then ends with the team showing little enthusiasm towards the proposed additions of the problem owner. Although the feedback of the problem owner can be classified as divergent, it does not appear to spark any new DT processes with the design team. This could be due to the stream of additions the problem owner proposes, which he thinks will make their idea better, without checking with the team how they view these additions in relation to their idea. All the proposed additions appear to stem from the assumption that the game needs to get more difficult over time. Yet this assumption is only communicated at the end of the conversation, keeping the team in the dark of the problem owner's true intentions for the most part of the dialogue. The 'new proposals'-example showcases the use of divergent feedback without it leading to DT behaviour in the design teams. Although proposals are a form of divergent feedback and could lead to DT behaviour, the example shows that this is not necessarily the case. It appears that only the divergent nature of the feedback is not enough to guarantee the start of a new DT processes and that something is still missing.

Our preliminary analysis of the feedback on other occasions – not preceding the fixation moments – indicates that hidden expectations and assumptions were less prevalent. Further comparison is however needed.

## **5. DISCUSSION**

The results of this explorative case study show reoccurring patterns in the feedback preceding the fixation moments of the design teams. Firstly, most of the feedback was convergent in nature and, additionally, the feedback that could be considered divergent did, for the most part, not spark any new DT processes within the design teams. We presume that one of the factors that hindered that the start of any new DT processes within the design teams was the presence of the expectations and assumptions the classmates and problem owner had about the design ideas, which were implicitly present in the feedback. Due to this implicit nature within the feedback, there was an absence of mutual understanding between the design teams and their peers and problem owner regarding these expectations and assumptions. If there is no mutual understanding, disagreement occurs and the openness, which is needed for a new DT process, is lost.

We suggest that, firstly, the feedback needs to be concrete and should clearly explain any expectations and assumptions the feedback giver might have about the design in order to reach a mutual understanding. When a mutual understanding is reached and it's clear for both parties what the feedback relates to, there is again room to regain openness and follow with a form of divergent feedback in order to spark a new DT process. We will explore these possibilities in our following case studies.

## **6. ACKNOWLEDGMENTS**

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# Perceptions and reality: Analyzing student experiences in ranking self and peer work through Adaptive Comparative Judgment

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This study investigated student capabilities in recognizing and predicting the relative quality of their own work and the work of their peers after participating in the Adaptive Comparative Judgment (ACJ) assessment process. Students participating in this study estimated their own ACJ-ranking for their design project in conjunction with ACJ exercises at the midpoint of the design project and once again at the conclusion. Student predictions were compared with the actual results from the ACJ sessions, with specific emphasis and further investigation performed for students with highly accurate predictions. Findings revealed non-significant correlations between students that could more-accurately predict their own rank and better performance. Further analysis demonstrated that female students were more accurate in their predictions of their rank and ranked better overall. Additionally, our analysis revealed that more accurately predicting students varied widely in numerous ways from total time spent on judgments, quantity of feedback given and received, and final ranking.

*Key words: assessment, self-perceptions, predicting achievement*

## 1. INTRODUCTION

Current research within education has a large emphasis on the improvement of student achievement and best practices in the classroom. However, there is limited understanding around student perceptions of their performance and their ability to predict their performance. Approaches such as data mining and observing student performance in previous classroom activities have been used by teachers and researchers to try to predict future student performance (Osmanbegović & Suljić, 2012; Romero, Lopez, Luna, & Ventura, 2013). However, there remains a lack of understanding of student self-perceptions of performance. The evaluation of student perceptions of personal performance may allow for better practices in the classroom that allow for improved student understanding of classroom materials.

To further investigate student performance prediction, the activity of design projects was used. Design projects, in this research, consisted of a classroom assignment which prompted students to create a visual artifact which incorporated individualized elements while also accounting for specific criteria and constraints. Although design projects have shown to be popular with students, the assessment of these projects, formative and summative, can be difficult because of the individuality of each assignment. One growing technique for assessment of design projects is adaptive comparative judgment (ACJ) (Kimbell, 2007, 2012a, 2012b; Pollitt, 2004, 2012; Pollitt & Crisp, 2004). Through ACJ, assessors are able to make comparative judgments when being presented with two assignments at a time. With a developed algorithm and software, ACJ systems use a series of comparative judgments, made by judges, and expedite the ranking process by ideally pairing similar assignments. ACJ has shown to be a reliable, simple, and valid process (Pollitt, 2012). While most research surrounding ACJ is summative (Bartholomew & Yoshikawa, 2018), recent efforts have suggested that using ACJ as a peer formative assessment tool, when compared to traditional peer assessment methods, can increase student achievement (Bartholomew, Strimel & Yoshikawa, 2018). By utilizing this method and practice, further

research may be possible to understand student perceptions of their performance, thinking, and personal experience during a design project.

This study examined 7th grade school students' (N = 130, 12-13 years old) perceptions of personal performance after participating in ACJ as a peer formative assessment tool on a two-week design project. The data collected includes the ranks and scores produced from the formative and summative peer assessments, comments given by students for peer feedback, and post-study questionnaire responses on personal performance from the participating students.

## **2. STATEMENT OF THE PROBLEM**

One motivational theory states that students are more motivated when they have positive self-evaluations (Harter, 1981). Throughout the use of ACJ, as a tool for both assessment and learning across all levels of education (Bartholomew & Yoshikawa, 2018), there remains a lack of research around student's self-perceptions of performance that results during ACJ's formative use. A recent study, aimed at investigating the formative use of ACJ as a peer assessment tool for middle school students, revealed that students participating in ACJ in the middle of a design task to collect and provide peer feedback reached significantly higher levels of improvement on the design task when compared to those who did not (Bartholomew, Strimel, & Yoshikawa, 2018). However, there remains little research into student perceptions and predictions of personal ranking associated with ACJ peer assessment. Student predictions of their own performance, and that of their peers, as it relates to the ACJ-produced rank at the midpoint and end of an assignment may provide valuable insight into student thinking, perceptions, and experiences.

## **3. RESEARCH QUESTIONS**

Recognizing the need to understand how accurately students could predict their rank and any potential relationships between this accuracy and student performance we investigated students' experiences with ACJ as a tool for both formative and summative assessment during a design project. Both qualitative and quantitative data were collected for the research, which consisted of student questionnaire responses, formative feedback provided through ACJ at the midpoint of the project, the ACJ produced rank order of student work at both the midpoint and conclusion of the project, and student scores received through traditional rubric-based assessment approaches. This data was used to answer the following research questions around student's experiences with predicting their performance, ACJ, and their actual performance.

RQ1: What difference, if any exists, between student predictions of their own ranking, produced through ACJ, and the actual ranking of students at both the midpoint and end of a design project?

RQ2: What relationship, if any exists, between students' ability to predict their rank and their achievement on a design project?

## **4. DESIGN PROJECTS**

In recent years, education has found an increase in the engagement of students through "active" learning approaches (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). One of these approaches are design projects where students are given specific criteria and constraints intended to meet specific learning objectives, but which also allow for personal creativity and autonomy while creating a visual representation (Ivers & Barron, 1998; Laamanen & Seitamaa-Hakkarainen, 2014). Benefits of design projects include students being more engaged in work as they increase in personal ownership (Nichols, 2016). While design projects have been found to be beneficial to students, there is a need to identify an improved application and assessment of these projects (Lammers & Murphy, 2002; Strimel, Bartholomew, Jackson, Grubbs, & Bates, 2017).

## **5. STUDENT SELF-PERCEPTION OF ACHIEVEMENT**

Studies from Bandura (1994) emphasized the relationships between one's self-perception of capabilities, motivation, and accomplishment. Studies stemming from this work continue to test student's self-evaluation, motivation and accomplishment (Schunk, 1991; Locke & Latham, 1990). Additional studies observed student self-perceptions and performance (Stevenson & Stigler, 1992; Uttal, Lummis, & Stevenson, 1988) and revealed that American students had higher self-perceptions but lower performance when compared to other students from Asian countries. Further, recent studies strived to develop an understanding of the relationship between a student's achievement and self-perception of achievement have been conducted (Shen & Pedulla, 2010).

Previous studies regarding student self-predictions found that there were no significant differences in prediction accuracy regarding sex, age, or academic class. However, students that accurately predicted their performance had greater self-acceptance (Keefer, 1971). A recent study with second language students in a biology course in higher education revealed that older students were slightly better predictors of their own performance than their peers were. It was also found that there was almost no difference between the students that did or did not speak English at home. Additionally, the ability to predict did not seem to influence performance in the course (Breckler, Teoh, & Role, 2011)

## **6. ADAPTIVE COMPARATIVE JUDGMENT**

Psychologist Louis Thurstone presented several alternative methods of constructing measurement scale to improve reliability in the educational assessment of open-ended scenarios. One of these models developed was the "Law of Comparative Judgment" (Thurstone, 1927). This model works on the basis that a person assigning a perceived phenomenon to an instantaneous value (i.e. traditional scoring approaches) will struggle to consistently assign the same value to similar work. Instead, Thurstone proposed that an assessor could simply progress through a series of comparisons where they were tasked with identifying the 'better' of two items. Thurstone argued that this approach to assessment was more reliable than the traditional value-based-judgment approach used in other forms of assessment (Thurstone, 1927).

Thurstone's work was revisited by Pollitt and Murray (1996) who used comparative judgment in conjunction with Georg Rasch's mathematical models for educational tests (Rasch, 1993). This allowed for the further development of the process of comparative judgment by allowing an individual to make a series of comparative judgments between different combinations of work. This produces a rank order for all compared work that is often significantly more reliable than traditional approaches to assessment (Pollitt & Whitehouse, 2012). Pollitt and others furthered this work using the advances in technology to improve the process of comparative judgment by automating the comparative process (Kimbell, 2008).

Additional work with the technological integration of comparative judgments yielded adaptive comparative judgment (ACJ). The adaptive trait refers to an algorithm embedded into comparison software which pairs similarly-ranked items for judgment as an assessor progresses through the process (Kimbell, 2012a, 2012b; Pollitt, 2012). Efforts involving the incorporation of ACJ in K-12 education have demonstrated success in using ACJ as a summative assessment tool (Davies, Collier & Howe, 2012; McMahon & Jones, 2015; Newhouse, 2011; Steedle & Ferrara, 2016).

## **7. METHODOLOGY**

This study took place in a large suburban school district located in the Midwestern United States. The school district is composed of a predominantly middle/upper-class population. One middle school teacher from this district was recruited based on interest in ACJ and a recommendation from the middle school's instructional coach. The participating teacher taught four class sections of 7th grade world history, consisting of 135 students. These four class sections were recruited for participation in the research over the course of four weeks of class time. The teacher created unique identifiers that were used for the student work, ACJ logins, and questionnaire responses to protect students. The teacher had sole access to the key for de-identifying any student data ensuring anonymity of student responses.



The participating teacher introduced all students in both groups to the design task posed for the assignment, which consisted of the creation of a travel brochure for clients seeking information for traveling in Southeast Asia (see Figure 1). All students were provided basic instruction around design principles and the use of computer-based design tools.

### Travel Brochure Challenge

**Assignment Description:**  
 You will serve as a travel agent for a small vacation to Southeast Asia. You will team up with three to four other students in class to form a travel agency that will appeal to several different types of families looking for different things, but all in the same part of the world. Your objective is to earn the business of as many of those families as possible. For the next two weeks, you will learn about, research and become an expert on this region of the world in hopes of being able to find a place for a family to take their trip of a lifetime. While doing so, you will create a one-pager about a specific country you would recommend based on a very basic family profile.

**Questions for Consideration:**  
 What do you would need to know to be able to help a family to make a decision on where to travel... lay of the land? Safety concerns? Budget? Tourist attractions that fit the family's desires? What else might you need to know in order to make a recommendation?

Name of County	Image Representing the Country
<p><b>History of Country</b></p> <ul style="list-style-type: none"> <li>Summary must include the BOTH the history of colonization AND independence of the country</li> </ul>	<p><b>Government &amp; Economy</b></p> <ul style="list-style-type: none"> <li>Type of government and its impact on the country</li> </ul>
<p><b>Government &amp; Economy</b></p> <ul style="list-style-type: none"> <li>Type of economy today and its impact on the country</li> </ul>	<p><b>Important Details of the country today</b></p> <ul style="list-style-type: none"> <li>GDP per capita</li> <li>Population and population density</li> </ul>
<p><b>Tourist Attractions</b></p> <ul style="list-style-type: none"> <li>Must include 2</li> <li>Demonstrated connections to family/client requirements per judges form</li> </ul>	

### Travel Agency Clients

**The Bartley Family**  
 The Bartley family is a very laid back, easy going vacation family. They LOVE the beach! Typically, they will go to the beach in Hilton Head, take a good book, and relax and read all day long. They tend to not want to do or book too many activities, as they view this time to get away, spend time together as a family and relax from their normal, very busy lives. While they aren't a big family for a lot of adventure, a little mixed in is ok, but make sure the resort they are staying in is top of the line. Mrs. Bartley loves learning about new and interesting cultures and doing some local shopping. While Mr. Bartley also enjoys learning of local culture, he's mostly interested in learning about and trying new cuisine. He loves to cook, so he's always looking for new ideas of how and/or what to make.

**The Little Family**  
 The Little family is young and has no kids. They are looking for adventure and nightlife to enjoy on their annual trip. When the Little family goes on a trip, they go all out... best of everything and they do it all! Beaches, adventure, relaxation, nightlife, shopping... you name it and they are up for it. They want to do as much as possible and money's no object. They love their coffee in the morning to get ready of the day and want to be surrounded by local culture. Thrills, nature, fine dining experiences... this is what the Little family lives for.

**The Loy Family**  
 The Loy family doesn't get out much. They would love to travel more. This trip will be a once in a lifetime opportunity. Their main priority is to see and do as much as possible for the least amount of money. They don't need the best accommodations, but with two young kids, the accommodations do need to be nice. So how can they travel as much as possible while there to see as much as possible on a tight budget? Mr. Loy doesn't like to sit still... reading on a beach or by a pool is not his idea of a great time. Mrs. Loy, however, would relax and read all day. Neither of the Loy kids love the water, but they do love animals and going to parks and sports. Mrs. Loy can shop with the best of them and Mr. Loy loves adventure. Both Mr. and Mrs. Loy love trying new things and authentic food, especially healthy food. To them though, the people help make the vacation. They really enjoy getting to know local citizens and spending time talking with and getting to know people.

**The Murphy Family**  
 The Murphy family is one active family. With 3 boys, all over the age of 10, they need some adventure and action. Golf anyone? Mr. Murphy loves to play golf while the boys love any kind of action or adventure they can get their hands on. If there are activities for kids, this family needs them... especially something that can allow Mr. and Mrs. Murphy to get away for some great scuba diving. They dive all over the world, but have never been to Southeast Asia. They are certified at one of the highest levels, so no waters are too dangerous for them. One of their favorite local places to visit here in the Midwest is Cedar Point, one of the largest theme parks in the country, so I'm sure they would love to experience some roller coasters on vacation if at all possible. As far as food, as you can imagine, with 3 boys, they love to eat. They don't care much about local authentic food, but one thing is for certain, when they go on vacation, the resort in which they're staying must be top of the line... no exceptions!

**The Abel Family**  
 Ms. Abel is a single woman looking for an adventure in Southeast Asia. She loves to travel and this is one part of the world she has never visited. When traveling she enjoys experiencing local sporting events and attractions. She loves the beach and nightlife and the finest of everything, especially fine dining experiences. This need to be unique and authentic so she has a great experience to be able to brag about to all her friends. Although she doesn't mind shopping, it's not her top priority when on vacation. Ms. Abel is looking to be pampered with the finest resorts while seeing and experiencing the adventures that Southeast Asia offers including sports, hiking, and wildlife.

Figure 1. Sample Assignment Description

The students picked a country, gathered data (information and images) and designed a travel brochure over the course of the first three class periods (90-minutes each). After these class periods, a draft was submitted as a PDF file by the students (Figure 2 displays a sample travel brochure uploaded by students) and the travel brochures were uploaded for peer evaluation.

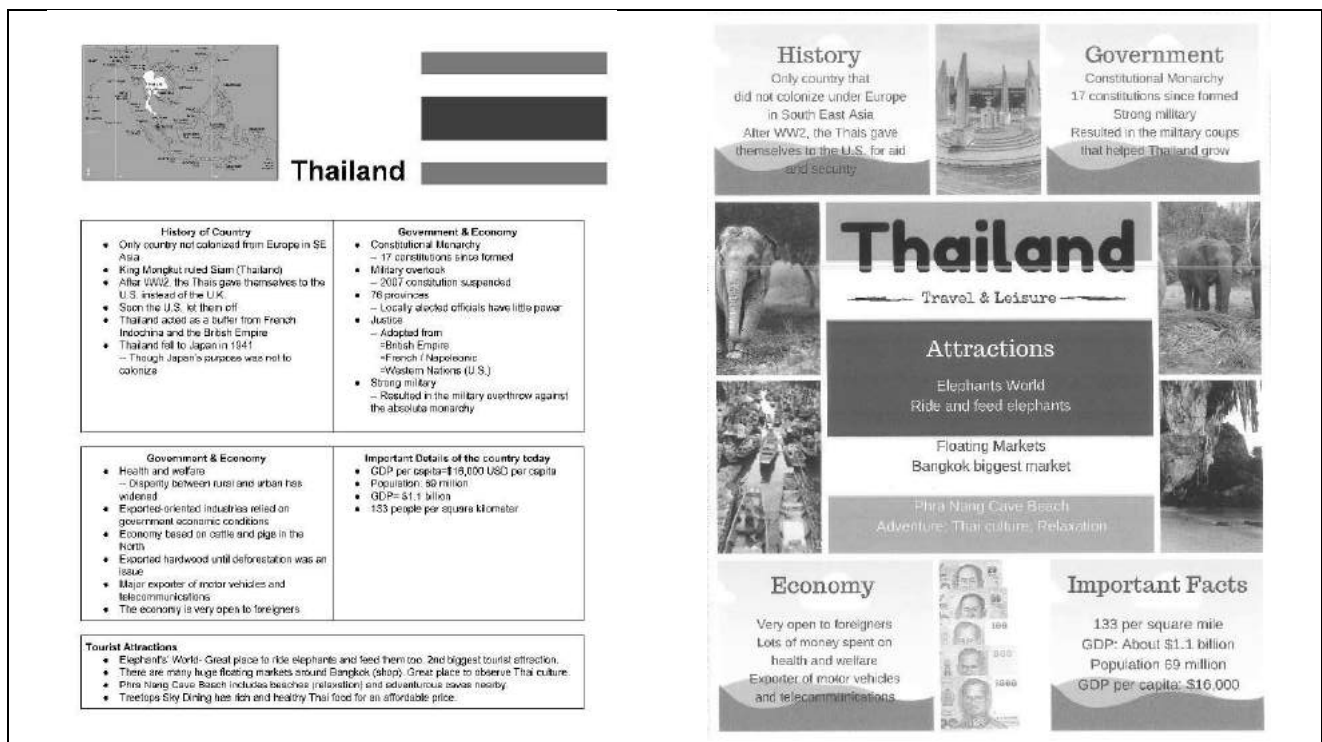


Figure 2. Sample Student Travel Brochure Uploaded at the Midpoint and Final to ACJ

Two classes of students participated in a peer-sharing and evaluation activity where they traded projects with other students and both gave and received feedback. The other two classes participated in the peer evaluation of all travel brochures produced by students participating in ACJ using ACJ assessment software called CompareAssess. Each student participating in the ACJ assessment was assigned an individual login used to complete 17 comparative judgements and provide anonymous feedback.

All students continued for the next five class periods to refine, revise, and improve their travel brochures. After two weeks, all the students submitted their final designs for assessment. All files from the students were uploaded to a final ACJ assessment session. The teacher along with students in the classes that previously did ACJ participated in this final ACJ session with each judge completing 30 judgments. This final ACJ assessment produced a final rank order of student work from all classes. The final rank order produced demonstrated a high level of reliability ( $r = .96$ ) and none of the judges demonstrated significant misalignment according to the Rasch Misfit statistics.

In addition to the other data all students from each class completed a post-study questionnaire which asked them to predict the rank of their own work at the midpoint and the final and provide other qualitative insight into the experience. All responses were recorded anonymously using the survey-instrument Qualtrics. These responses were matched with the unique student identifiers created by the teacher and recorded for data analysis.

## 8. FINDINGS

The findings from this research were taken from several sources including the student questionnaires, the ACJ-facilitated rank order and feedback, and the scores received through the traditional grading approach. Prior to analysis, all collected data was conditioned to ensure fidelity of results. Statistical analysis software (SPSS Version 24) was used for quantitative data analysis. The findings will be presented here in alignment with the corresponding research question.

***RQ1: What difference, if any exists, between student predictions of their own ranking, produced through ACJ, and the actual ranking of students at both the midpoint and end of a design project?***

The first research question guiding this effort involved several statistical procedures to investigate how accurately students were able to predict their rank for the assigned design project. Importantly, students predicted their rank out of all participating students ( $N = 135$ ) as opposed to with the students enrolled in their class section only. This was done at both the midpoint and the conclusion of the project.

The initial tests involved two one sample t-tests to investigate if the student's predictions were statistically significant from their actual ranks. In both cases, at the midpoint and the conclusion of the assignment, the students' predictions were significantly different from their actual ranks; Midpoint ( $M = 9.54$ ,  $SD = 7.50$ ,  $t(25) = 6.49$ ,  $p < .001$ ), and Final ( $M = 22.70$ ,  $SD = 18.17$ ,  $t(25) = 6.37$ ,  $p < .001$ ). These findings show that students were more accurate in their predictions at the midpoint than at the final when predicting their individual rank in the overall rank order.

Recognizing gender as a potentially significant factor in student's ability to predict their own performance a point-biserial correlation was conducted between gender and the difference in their predicted and actual ranks for both the midpoint and the final. The relationship between gender and student's ability to predict their rank at the midpoint was not statistically significant,  $rpb = .24$ ,  $p > .05$ . Conversely, for the student's predictions and final rank, the relationship demonstrated that females were better at predicting their ranks than males,  $rpb = .61$ ,  $p < .001$ .

***RQ2: What relationship, if any exists, between students' ability to predict their rank and their achievement on a design project?***

The second research question investigated student's abilities to predict their rank and their achievement—as obtained through the final student-produced rank order and the traditionally-assigned grades from the teacher. A Spearman correlation between the student's final rank and the difference in their predicted rank and their final rank was conducted which revealed a significant correlation,  $r_s = .88$ ,  $p < .001$ . This suggests that students who were better predictors on their final rank were ranked better in the final ACJ session.

In addition to the previous correlation, a Pearson's correlation was conducted to investigate the relationship between student's ability to predict their grades and the final grades received by the teacher through traditional scoring approaches. The first correlation test investigated student's prediction accuracy at the midpoint and their final grades and the results did not demonstrate a significant relationship,  $r = .16$ ,  $p > .05$ . However, the results from the correlational tests investigating the relationship between student's prediction accuracy and their final rank approached significance,  $r = -.38$ ,  $p = .055$ . These findings suggest that students who were better at predicting their rank performed better – based on the traditionally assigned grades from the teacher.

## **9. CONCLUSION**

ACJ has continued to gain traction as a highly-reliable and effective method of assessment for open-ended design problems. The by-products of the ACJ process, which includes a rank order of student work and a collection of comments collected in conjunction with each judgment made in the process, can provide valuable data for both formative and summative assessment as well as for informing instruction and providing insight into design values of different populations. For example, research has demonstrated that students acting as judges in the ACJ process can improve their own learning, achievement, and design abilities. However, the lack of understanding around the ways in which students perceive and rank their own work as well as the work of their peers when engaged in the ACJ process as a peer formative assessment tool should be emphasized. Therefore this study sought to better understand student's experiences and perceptions of their own standing in an effort to examine the relationship between the student's self-evaluation and accomplishment. Specifically, this study aimed to set a foundation for building upon the work of Bandura (1994) on self-efficacy which suggests that efficacious people can approach difficult situations with a confident mindset that can reduce stress, while people who doubt their own abilities will give up more readily in the face of adversary. Accordingly, the research questions guiding this effort investigated the relationship between student predictions of their own ACJ ranking and the actual ranking in regards to their design project and then examined the relationship between their ability to predict their rank and their achievement on the design project.

Although not all significant, the findings did reveal correlations between students that could more-accurately predict their own rank and better performance—as identified by the ACJ rank and the teacher assigned grades. Further analysis also revealed that male students were more accurate in their predictions of their rank but female students ranked better overall. In addition, the data analysis suggests that students were better able to predict their ACJ ranks at the midpoint of their design project than at conclusion of the project.

We feel it important to note that our analysis showed that almost all students expected to perform better on the final than they had on the midpoint rank. Further almost all students had an inflated perception of their own ranking – they expected to rank better than they actually did, and as such, almost everyone guessed a higher rank for the final than the midpoint which may have resulted in an inflated difference in the final predictions. According to the results of this study, it may be beneficial for teachers to engage students in the ACJ process as a formative assessment learning tool for evaluating their work and the work of their peers while being transparent in the actual rankings. This process may help students to understand the values of “good” design, analyze exemplars of projects within different “quality” ranges, become better predictors of success, and potentially build their self-efficacy in design and design assessment. Further research efforts, such as this and ones that dive deeper into the development of self-efficacy and values of design, may assist in educators using the ACJ approach to its full potential in regards to both assessment and learning.

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# Teaching Sustainability in Technology Education: Perception Versus Practice

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This paper is part of a study which aims to promote a sustainable global future through Technology Education (TE) at Second Level in Ireland. This paper examines the perception and practice of teachers and trainee teachers in relation to educating for sustainability in TE. These subjects are well placed to drive social change that contributes to a sustainable future as they integrate the design of products, the consumption of materials, and product lifecycle assessments to name but a few. In order to examine the teaching of sustainability in Second Level TE it is necessary to consider teachers' understanding of sustainability as a concept (perception) and their actions in educating for it (practice). This was achieved through an online survey disseminated to teachers and student teachers with teaching experience in Irish Second Level TE. The survey sought to investigate teachers' understanding of the concept of sustainability and how educators are (or are not) teaching for sustainability. From 140 participants, the survey findings identify a consistent understanding of the concept of sustainability across the profession. The results illustrate that 81.2% of teachers are teaching for sustainability within TE subjects. However, the frequency of which varies widely among the educators surveyed. The findings indicate that 96% of participants recognise the importance and benefits of incorporating sustainability into their teaching. Despite recognising these benefits however, a majority of participants also highlighted the many limitations/challenges which hinder the teaching of sustainability in practice. These findings highlight the need for further integration of sustainability into TE given the subjects' scope to drive social change towards a sustainable global future.

*Key Words: Sustainable education, Sustainable development, Technology education.*

## 1. INTRODUCTION

### *1.1 Context / Background*

Sustainability has gained increasing momentum in recent years with many policy makers seeking to address sustainability issues such as the major threats of climate change and global warming facing our planet. For instance, in 2015 the Paris Climate Agreement saw world leaders pledge for the first time to limit global warming to below 2°C (European Commission, 2016). However, more recently the United States President withdrew the USA from the Agreement (Shear, 2017) and referred to climate change as “a hoax perpetrated by the Chinese to damage US industry” (Clark, 2016, p.1). The rise of opinions such as these has led to increasing concern for the societal outlook and attitudes of future generations towards climate change.

A recent study carried out by the New-Climate Institute & Climate Action Network found that Ireland is currently the worst performing European country in the Climate Change Performance Index. This study found that Ireland has fallen twenty-eight places to forty-ninth out of fifty-six countries ranked in the 2018 Climate Change Performance Index, behind China placed at forty-one. According to experts, Ireland is poised to be one of the few EU countries to miss its 2020 emissions reduction targets and is “nowhere close to being on track concerning its well-below-2°C compatible pathway with both its current level as well as its 2030 target” (Burck, et al 2018, p.6). Such figures are cause for concern and highlight the need for changes in society's attitude towards sustainable development.

## **2. LITERATURE**

### ***2.1. Defining Sustainability***

Despite its publication in 1987, the Brundtland Commission's Report titled 'Our Common Future' has provided one of the most widely cited definitions of sustainability (1987). The report defines sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p.37). This primarily emphasises environmental sustainability, but also encompasses economic, social, cultural, educational, and recreational sustainability (Grimes, 2011). Throughout this paper the terms 'sustainability' and 'sustainable development' will be used interchangeably.

### ***2.2. Teacher Practice, Educating for Sustainable Development***

Throughout TE there is a potential to reduce greenhouse gas emissions and combat climate change. This is made possible given the subjects learning outcomes focusing on recycling, product redesign, and conservation processes. This allows TE to be a positive contributor to the goal of sustainable development (Pavlova, 2018).

Uitto and Saloranta (2017) in 'Subject Teachers as Educators for Sustainability: A Survey Study' examined the perceptions of Finnish secondary school teachers as educators for sustainability. From 49 schools in Finland, 442 subject teachers were surveyed. One aspect of the results revealed evidence that Finnish TE (Crafts) is one of the poorest performing STEM subjects in terms of educating for environmental sustainability (Uitto and Saloranta, 2017).

Other countries, such as New Zealand, have curriculums which integrate teaching sustainability in TE. New Zealand's TE is comprised of six strands, three of which incorporate sustainability as indicators of expected student performance. These strands are design in technology, manufacturing and design, and visual communication (Pavlova, 2018).

Ireland's National Strategy for Educating for Sustainable Development 2014 – 2020 outlines the policy in terms of educating for sustainable development (ESD). It identifies eight action areas of priority which were assessed by the challenges and potential opportunities they pose (Department of Education and Skills 2014, p.5). Despite such ambitions to improve ESD, Ireland's current TE syllabi contain a marked absence of any real emphases on sustainability. While there may be a surface level reference to environmental issues, McGarr notes that TE has far more potential to embed further and deeper elements of educating for sustainability (McGarr, 2009). Opportunities to integrate ESD have been identified in the Irish syllabi in the areas of production and consumption patterns, corporate responsibility, environmental protection, natural resource management and biological and landscape diversity (McGarr, 2009). Such integrations could support teachers' perceptions and practices in the context of sustainability in TE.

### ***2.3. Teachers Perceptions of Sustainability***

Differences in teachers' perceptions of ESD are evident throughout the literature. For instance, Elshof (2005), Hill and Elshof (2007), Pitt and Lubben (2009), and Pavlova (2012) found differences in teachers' perceptions of ESD and in their level of readiness to address such elements (Pavlova 2018).

Elshof's study set out to identify which facets of sustainable development teachers deem to be the most significant from a personal, collegial and student interest perspective. Elshof highlights the importance of moving trainee teachers away from the uninterested, doubting and denying quadrants of his below perceptions and commitment chart (Figure 1). Elshof emphasises that these teachers need to move toward the engaged and aware quadrant as it is from this perspective that teachers can become proactive proponents of sustainable practices and design (2005).

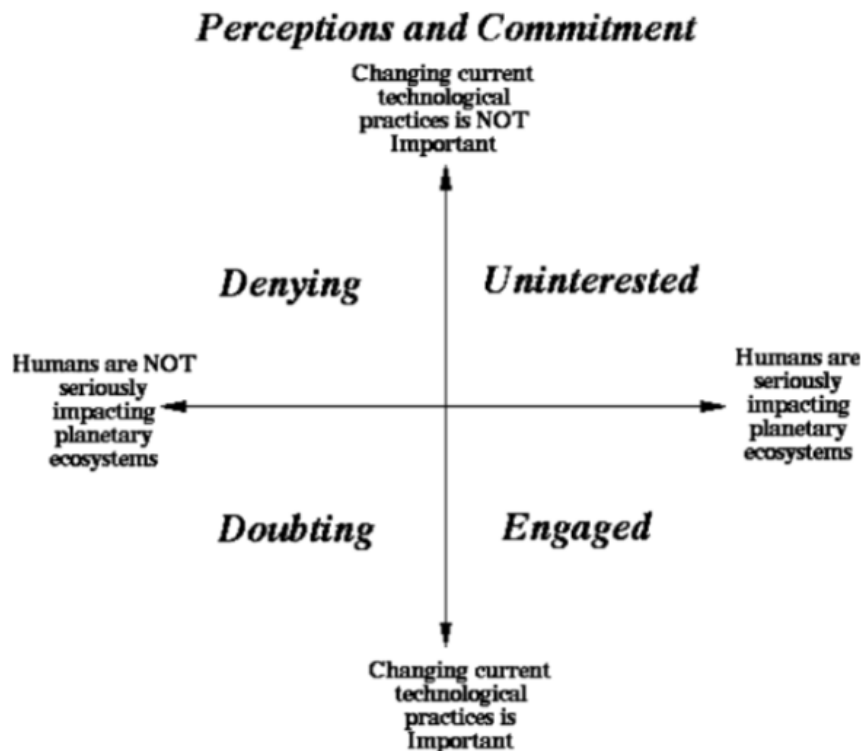


Figure 1. Perceptions and Commitment of Teacher's Interpretation of Sustainable Development (Elshof, 2005).

Pitt and Lubben suggest a hierarchy in terms of teachers' awareness of the social dimension within sustainability and teachers' approaches to incorporating this into their teaching. Their findings suggest that some teachers are reluctant to promote the social dimension of sustainability as they find the inclusion of foreign design contexts problematic. Such teachers are reluctant to include concepts such as cultural diversity, fostering traditional wisdom and the enhancement of human rights (Pitt and Lubben, 2009, p.181).

In contrast, Pavlova's survey of African TE academics' perceptions of ESD found that all participants believe in the importance of addressing sustainable development through TE. It was also demonstrated that participants prioritised the social factor of sustainability, although it was acknowledged that this needs to be framed by environmental concerns. Additionally, participants prioritised a value-change approach to sustainable development (Pavlova, 2012).

Pitt and Heinemeyer analysed learning resources prepared by the Ellen MacArthur Foundation for Design and Technology (2015). The Ellen MacArthur Foundation is a charity that seeks to inspire learners to re-think the future through the circular economy framework (MacArthur, 2017). One element of the study involved interviewing British TE teachers and industry professionals after they had participated in Teardown Labs. They found that 83% of participants strongly agreed that sustainable design and development was of relevance to their work. Despite the recognised importance of ESD, researchers found that many participants came to the workshops with pre-existing mental models of sustainability. This in turn hindered their ability to distinguish models of sustainability, with many simply overlaying one set of concepts with the other (Pitt and Heinemeyer, 2015, p.257).

Furthermore, when Uitto and Saloranta examined the perceptions of Finnish secondary school teachers as educators for sustainability they found that there were significant differences between the subjects in terms of the teachers' perceptions of their competence to educate for sustainability. Additionally, the frequency with which they taught about the different dimensions of sustainability, such as ecological or social sustainability, also varied (Uitto and Saloranta, 2017).



## 2.4. Grounding Current Research

The move to a more sustainability oriented TE syllabi requires a transition away from simplistic linear notions of design to manufacture to use to disposal of products. It is such linear thinking which has led to current consumption-driven manufacturing systems that result in products which are designed to end their lives in landfill (Grossman 2006; Slade 2006) cited in (Elshof, 2008). A potential solution, Elshof suggests, is the enormous opportunity for TE to shape young minds and create new models of sustainable development/consumption (Elshof, 2008).

Similarly, McMahon and Bhamra suggest that given the changing nature of design, it is important that designers are equipped with the skills and knowledge that will enable them to participate in the move towards a more sustainable global future (2016). Stables agrees, suggesting that designers have the power to envision a future where nothing is recycled (2008, p. 217). TE subjects are ideally situated to initiate the development of such a sustainable outlook.

In order to achieve such a transition it is first necessary to investigate current teacher practices/perceptions of sustainability in TE Ireland. While ESD seeks to influence the values, interests and attitudes of students, little is known about the effectiveness of educating for sustainability (Uitto and Saloranta, 2017). Pavlova highlights the importance of conducting further studies to identify the appropriate pedagogy that should be applied (2018, p.837). This paper seeks to add to the body of research on sustainable education by considering the perception and practice of TE teachers in Ireland.

## 3. METHODOLOGY

### 3.1. Research Methodology

This research aims to analyse the perceptions and practices of the teaching of sustainability in TE Ireland. This paper represents part of a larger study which employed an Action Research methodology. This was applied to bridge the gap between research and practice (Somekh, 1995). The research aim represented in this paper was achieved through the implementation of an online survey. The goal of this survey was to gain insight into perception/practice thereby making action research the predominant methodology used (Glenn et, al. 2017, p.30).

### 3.2. Participants

Survey participants were experienced TE educators. Table 1 and 2 outline the sample size calculations of the population surveyed. These sample sizes are involving a 90% confidence interval in answers from the surveyed population. The sample size was determined based on the Department of Education Skills Statistics (DES).

The population size for TE trainee teachers is based on the number of trainee teachers who have completed teaching practice (undergraduate LM094/95).

Table 1. Sample size for Irish Leaving Certificate Level, figures taken from (DES Statistics 2016/17) (tab 4.17 statistic

Subject:	Number (count)	
	<i>Pupils</i>	<i>Teachers*</i>
Construction Studies	18,516	772
Technology	3,096	129
Engineering	12,002	500
Design Communication and Graphics	12,218	509
<b>Total population:</b>	<b>45,832</b>	<b>1,910</b>
<b>Sample size involved in this study:</b>	<b>240 for 90% Confidence interval</b>	

report).

*\*The most accurate information would take into account that teachers may teach at both Junior and Leaving Certificate Level. This is why **Leaving Certificate Level teachers will be used as the teacher population**. This ensures that teachers are not double counted.*

*Table 2. - Sample size for LM094 and LM095 (approximation).*

Course:	Students (count)
Bachelor of Technology (Education) in Materials and Architectural Technology LM094	60 per year
Bachelor of Technology (Education) in Materials and Engineering Technology LM095	40 per year
<b>Total number over 3rd/4th years:</b>	<b>200</b>
<b>Sample size:</b>	<b>115 for 90% Confidence Interval</b>

Based on Cohen, et al. (2007) the sample size for this study should be approximately 115 trainee teachers and 240 teachers. G\*Power analysis software determined that the sample size could be increased to N = 177 trainee teachers and N = 247 teachers in order to answer research objectives using both correlation analysis and multiple regression analysis.

The total amount of teachers and trainee teachers whose data was used in this study is shown in the table below. The required amount of teachers and student teachers was not achieved to validate a 90% confidence interval in the data. However, the purpose of this study is simply to gain an insight into the perceptions and practices of TE teachers in Ireland, rather than to draw generalisable conclusions.

Overall, the survey received 145 participants. This was made up of 55 trainee teachers, 5 teachers teaching outside of Ireland and 85 teachers teaching within Ireland. The 5 teachers teaching outside of Ireland were not taken into account in this study as the aim of the study is to look at current practices within Irish TE at Second Level. Therefore, a total of 140 participants were used to gather this data.

*Table 3. - Experience of population survived in study.*

Cohort Experience Teaching	No. of Cohort
Trainee Teachers	55
Less than 1 year	7
Between 1 - 3 years	18
Between 3 - 7 years	17
Between 7 - 15 years	21
Between 15 - 20 years	8
More than 20 years	14

### **3.3. Survey Approach (Research Design)**

Surveys were carried out using an online survey platform. Ethical approval was obtained, surveys were developed, piloted and refined. After refinement, the survey was disseminated to participants with teaching experience in TE, outlined in Table 3.

Overall, the survey consisted of 10 questions, many of which included sub parts divided into a),b),c). The questions comprised both qualitative and quantitative aspects. The quantitative questions were designed using a 5 point Likert scale. This allows participants to express the extent to which they agree or disagree with a particular statement or question. Additionally, it allows researchers the freedom to fuse measurement with opinion, quantity and quality (Cohen et, al. 2007). Qualitative style questions were also used to allow participants the opportunity to express their views, values and attitudes throughout their answers (Cohen et, al. 2007). This qualitative data was then coded to allow for thematic review.

#### 4. RESULTS

**Q1. Perception - To what extent do you agree or disagree with the following statement: “Climate change and global warming are a hoax”.**

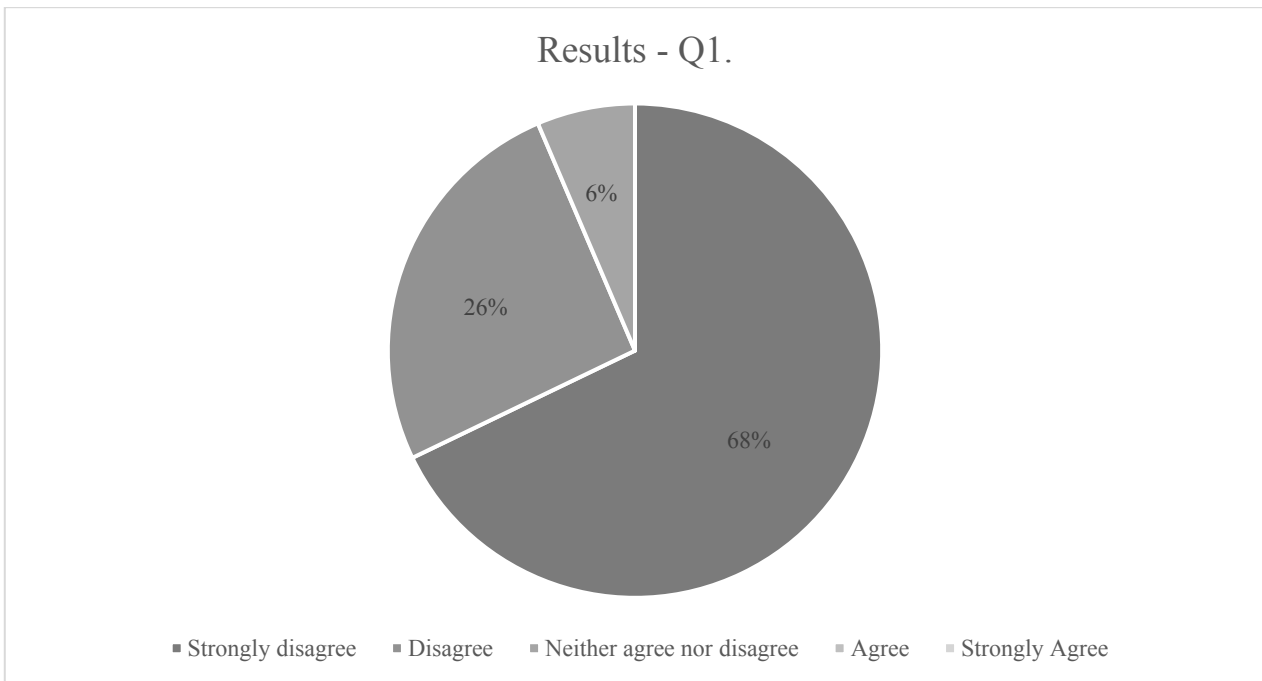


Figure 2. Participants level of agreeance with the following statement “Climate change and global warming are a hoax”.

No participants ‘agreed’ or ‘strongly agreed’ with this statement. 67.9% of participants ‘strongly disagreed’, 25.7% ‘disagreed’ and 6.4% ‘neither agreed nor disagreed’.

**Q2. Perception - In your own words, please briefly describe what the term "sustainability" means to you?**

Participants’ answers were coded into themes represented in Table 4. These can broadly be categorised as either material based or societal protection based. For instance, a response such as “using materials which are not harmful to the environment to process” is material based. Whereas, a response such as “reducing the level of damage to the environment today to protect it for future generations” falls into the category of societal protection.

Theme	% Theme identified
Environment	29.83
Resource	24.53
Material	18.32
World and planet	11.35
Future generations	11.09
Maintain and sustain	10.98
Design	9.63
Product	9.26
Economical	3.99
Future	3.37
Responsible	1.46
Economy	1.31
Society	0.87

Table 4. Results of coded themes identified in participants' definitions of sustainability.

**Q3. Perception - To what extent do you agree or disagree with the following statement: "It is important to teach future generations about responsible consumption and production patterns."**

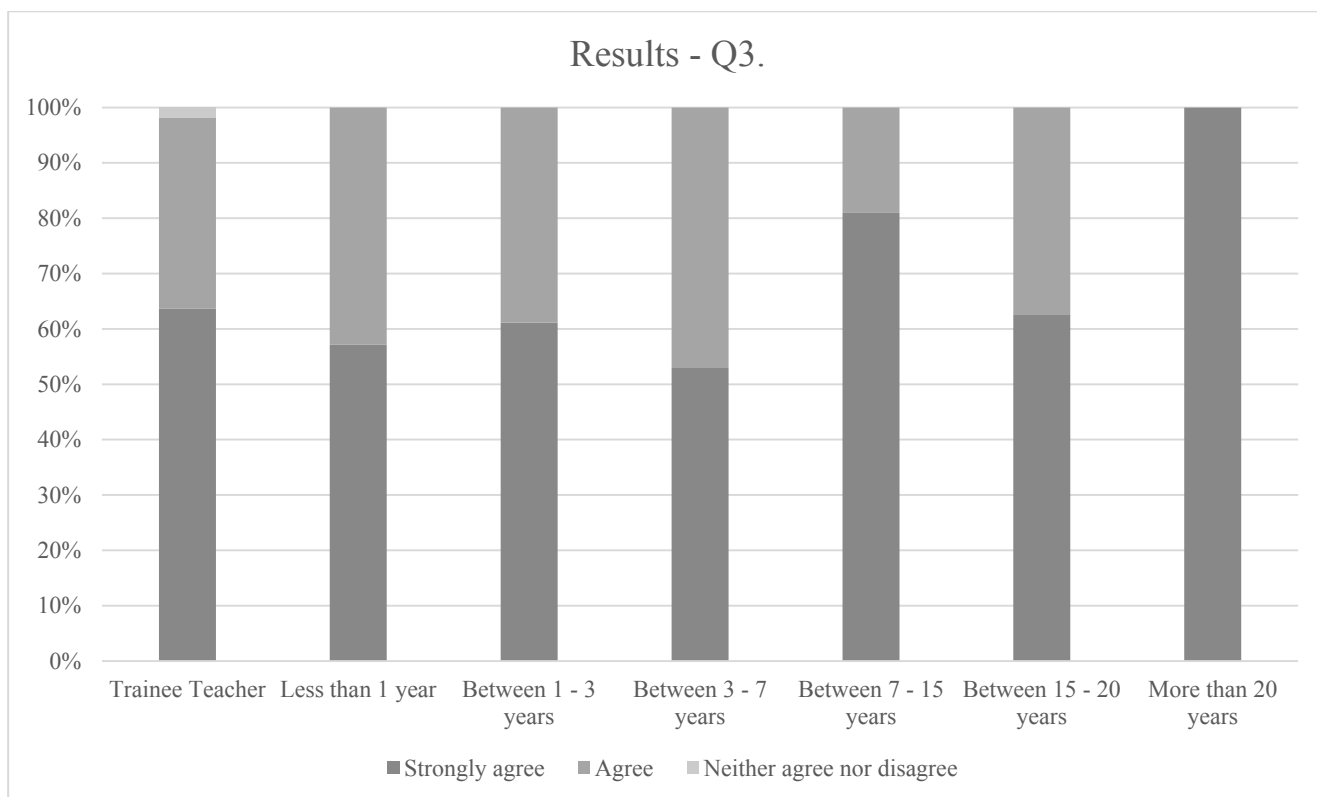


Figure 3. Shows teachers agreeance with the following statement "It is important to teach future generations about responsible consumption and production patterns".

Almost all 140 participants were in agreeance with the above statement; 67.9% strongly agreed, 31.4% agreed, and 0.7% neither agreed nor disagreed.

Q4(a). Practice - Do you teach your pupils about sustainable practices? For example: Up Cycling, Life Cycle Assessments, Cradle to Cradle, Environmental Design, ECO Design, Regenerative Design, Green Design etc.

For the purpose of validity, only responses from participants currently teaching in schools where used in this data set. This is due to trainee teachers only having a minimum of 6 weeks or a maximum of 10 weeks school placement.

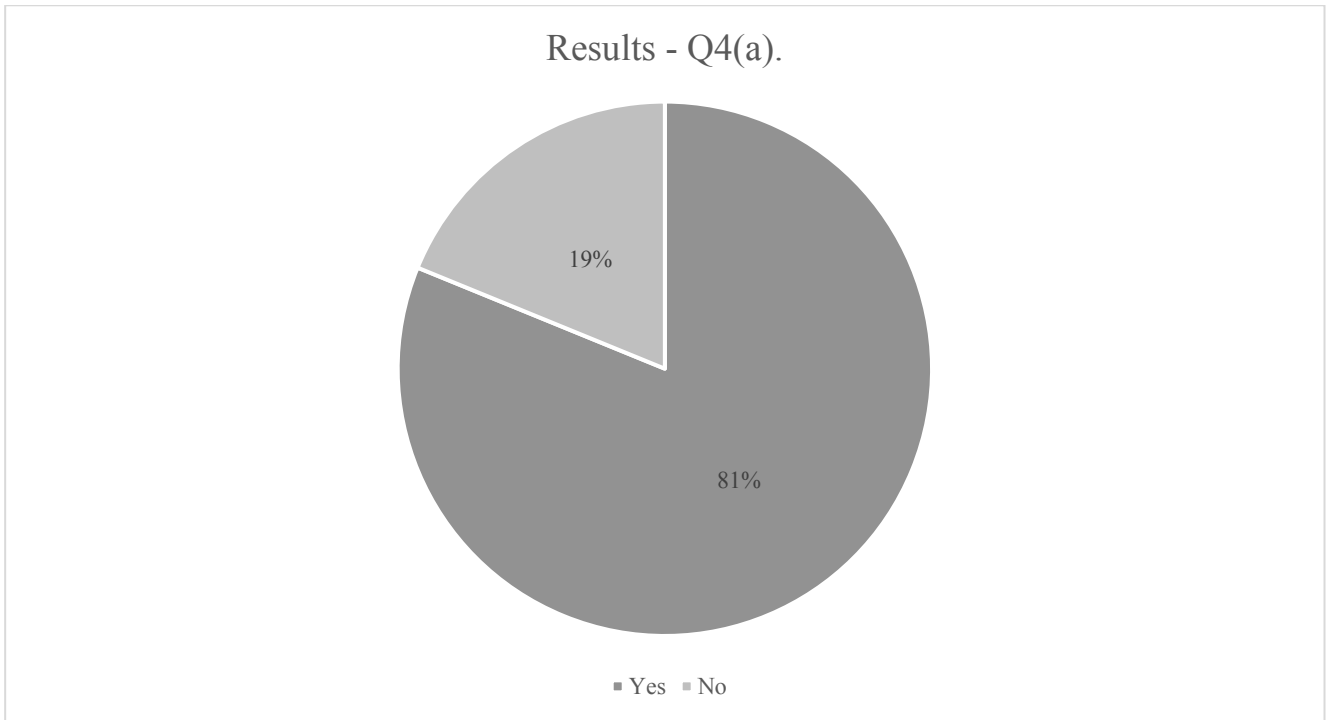


Figure 4. Shows the number of teachers that teach pupils about sustainable practices.

81.2% of teachers said ‘yes’ they teach for sustainability. 18.8% of teachers said ‘no’ they do not teach for sustainability. Participants who answered ‘yes’, were then asked a subsequent question of how often they teach for sustainability.

**Q4(b). Practice - How frequently do you teach your pupils about sustainable practices?**

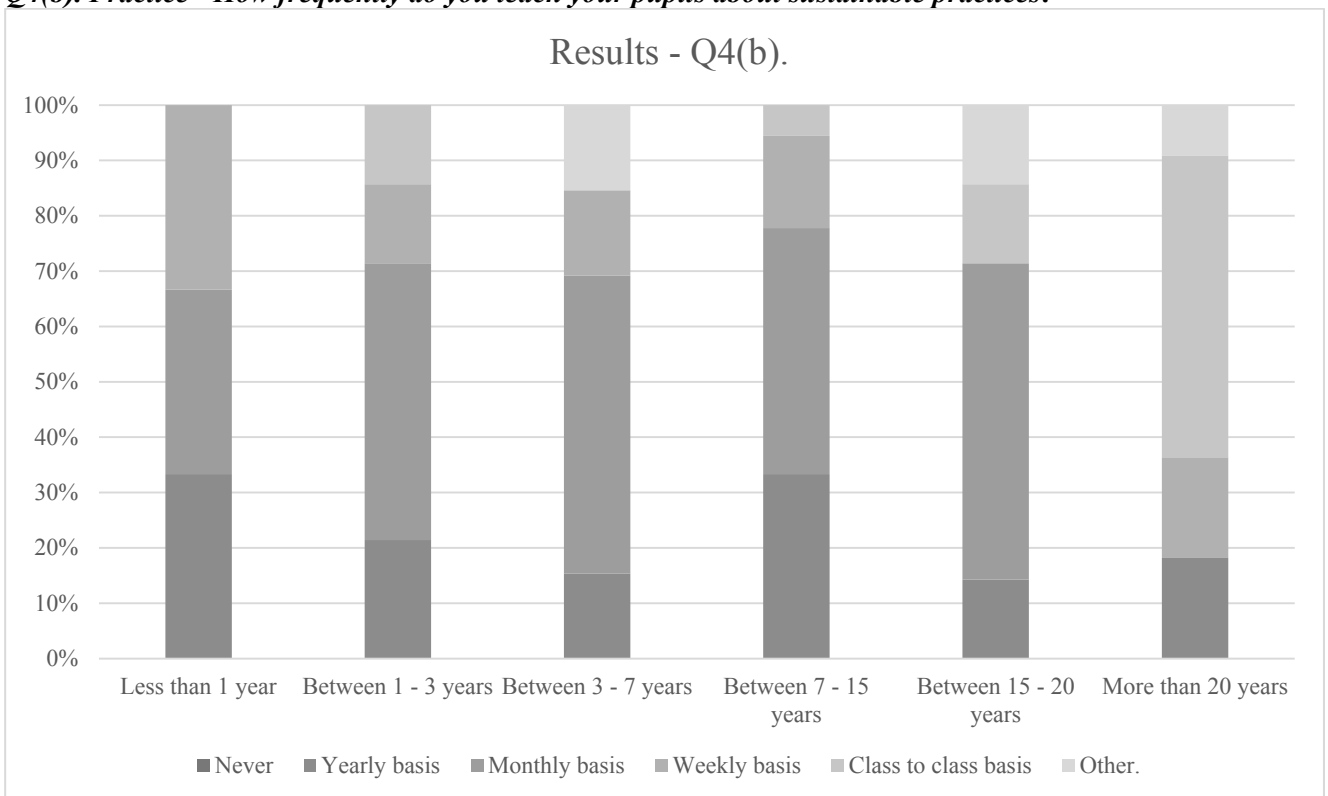


Figure 5. Participants (69 teachers). Bar chart represents the frequency of teachers teaching for sustainability.

Table 5. Participants (69 teachers). Table outlines who answered 'yes' to teaching for sustainability and the frequency in which they teach it.

	Never	Yearly basis	Monthly basis	Weekly basis	Class to class basis	Other
Less than 1 year	0	2	2	2	0	0
Between 1 - 3 years	0	3	7	2	2	0
Between 3 - 7 years	0	2	7	2	0	2
Between 7 - 15 years	0	6	8	3	1	0
Between 15 - 20 years	0	1	4	0	1	1
More than 20 years	0	2	0	2	6	1
TOTAL	0	16	28	11	10	4

Of the 81.2% who answered 'yes'; 14.5% of teachers teach about sustainable practices on a class by class basis, 15.9% on a weekly basis, 40.6% on a monthly basis, 23.2% on a yearly basis, and 5.8% selected other.

**Q5. Perception - Can you see any restrictions, challenges, or limitations when it comes to integrating sustainability into technology subjects?**

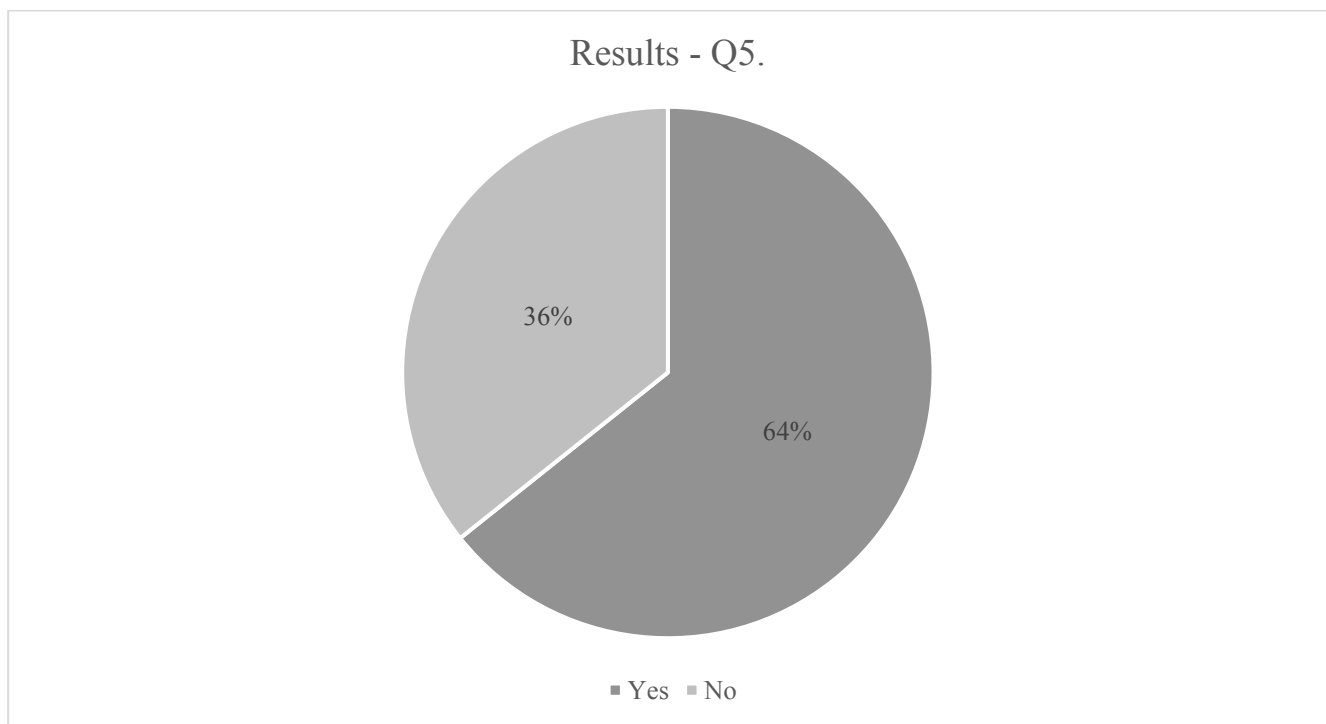


Figure 6. Percentage of participants who see restrictions, challenges, or limitations to integrating sustainability into TE subjects.

64.3% of the participants answered 'yes' and 35.7% of participants answered 'no' to whether they see any restrictions, challenges, or limitations to integrating sustainability into TE subjects.

**Q6. Perception - Can you see any opportunities or benefits when it comes to integrating sustainability into technology subjects?**

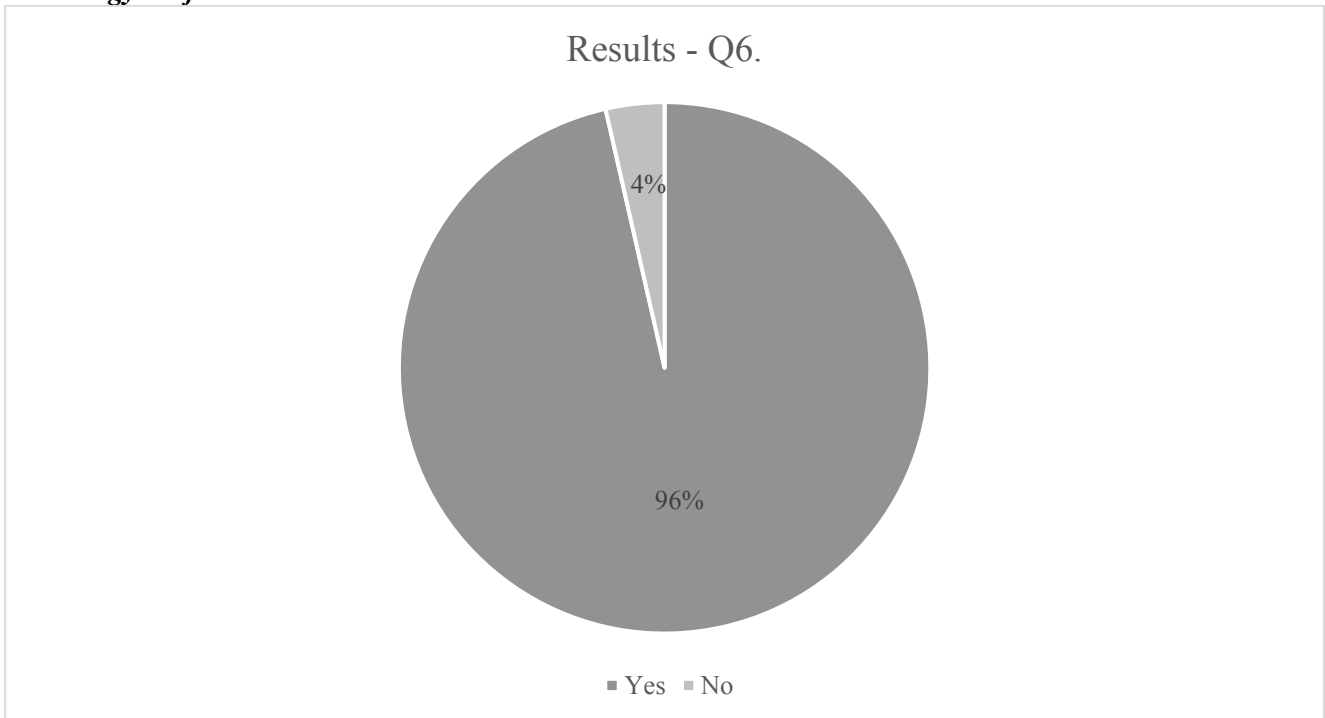


Figure 7. Participants believe that there are opportunities or benefits to integrating sustainability into TE subjects.

96.4% of participants indicated that they see opportunities or benefits to integrating sustainability into TE subjects. However, 3.6% of participants answered that they do not see any.

## 5. DISCUSSION

**Q1. Perception - To what extent do you agree or disagree with the following statement: "Climate change and global warming are a hoax".**

The majority of participants surveyed were in close agreement, with 93.6% indicating that they either 'disagreed' or 'strongly disagreed' with the above statement. No participant indicated that they 'agreed' or 'strongly agreed'. However, 6.4% of participants selected that they 'neither agreed nor disagreed' with the above statement. While climate change and global warming are just two aspects of sustainability, they provide an insight into the opinions and values of participants on this topic.

The findings highlight that we as educators are not in complete agreement given that a small segment of those surveyed are neutral on the existence of climate change and global warming. As educators we serve as role models for future generations, yet we are not in agreement on two of the biggest sustainability threats facing our planet. In one aspect of their study, Elshof and Hill found that "teachers' knowledge about the environment and sustainability were influenced by both the media as well as professional and personal experience" (Elshof and Hill, 2007, p.248) Could the increasing rise of climate change denial and "fake news" be influencing the opinions of teachers?

***Q2. Perception - In your own words, please briefly describe what the term "sustainability" means to you?***

77.27% of participant answers fall into the themes outlined in Table 4. These answers indicate a consistent understanding of the concept of sustainability across the profession encompassing themes which include the environment, design and resources. The below participant answer reflects an in depth understanding of sustainability:

“Living in a manner that allows future generations to live in a safe, clean environment e.g. leaving the world with as neutral a carbon footprint as possible. We should leave the world at least as sustainable as we found it, or ideally improve on its environmental status for future generations.”

In addition to 77.27% of the referenced answers, the remaining 22.37% were not coded as their definitions fell outside the above themes. Examples of such answers which did not satisfy the themes described in Table 4 include: “trying to keep something going”, “will never run out” and “the wise use of something”. Such answers arguably imply an understanding of sustainability, albeit at a surface level.

***Q3. Perception - To what extent do you agree or disagree with the following statement: “It is important to teach future generations about responsible consumption and production patterns.”***

None of the participants ‘disagreed’ or ‘strongly disagreed’ with the above, indicating that teachers and trainee teachers understand the importance of educating about responsible consumption and production patterns.

Interestingly, when participant results were categorised by years of teaching experience, all teachers with 20 years or more experience indicated that they strongly agreed that it is important to teach future generations about responsible production and consumption patterns. Teachers with 20 years or more experience account for 10% of participants. Similarly, Borg et, al.’s nationwide survey study of Swedish teachers at second level found that recently qualified teachers had a poorer understanding of sustainable development than teachers with more than five years’ experience (Borg et, al. 2014). In contrast, Summers et, al. found that UK student teachers had a more comprehensive understanding of sustainable development than their mentors and more experienced teachers (Summers et, al. 2005). Further research is needed on this aspect of the study in order make a determination as to the reason for such attitudes among more experienced teachers.

***Q4(a). Practice - Do you teach your pupils about sustainable practices? For example: Up Cycling, Life Cycle Assessments, Cradle to Cradle, Environmental Design, ECO Design, Regenerative Design, Green Design etc.***

***Q4(b). Practice - How frequently do you teach your pupils about sustainable practices?***

81.2% of participants (69 teachers) selected ‘yes’ indicating that they teach for sustainability. Participants who answered ‘yes’, were then asked a subsequent question of how often they teach for sustainability.

18.8% of teachers selected ‘no’ indicating that they do not teach sustainability. Elshof suggests that some teachers avoid teaching their pupils about sustainable design issues and how these relate to technological design and manufacturing as they believe that pupils will not find them interesting, relevant and empowering (Elshof, 2005).

Despite the majority of participants indicating that they teach their pupils about sustainable practices, the results show that the frequency of this varies widely among the educators surveyed. Of the 81.2% of teachers who answered ‘yes’, 40.6% of these only teach about sustainable practices on a monthly basis. 14.5% of participants indicated that they teach sustainability on a class to class basis.

When asked where in their teaching do participants teach for sustainability the majority of respondents offered surface level answers which only identified one area of the subject such as, the design stage or the evaluation



stage of projects. On the other hand, few participants demonstrated that they frequently teach about sustainable practices. For instance, commenting that they “[teach for sustainability] throughout, I lead by example.”

This sub-question data seems to indicate that while 81.2% of participants teach about sustainable practices, in practice, sustainability is incorporated into their teaching infrequently. Only a minority of “devotees” demonstrate what Pitt and Lubben terms a ‘frame of mind’ approach, meaning that they frequently ground their teaching in terms of sustainability (2009, p.181).

***Q5. Perception - Can you see any restrictions, challenges, or limitations when it comes to integrating sustainability into technology subjects?***

64.3% of participants answered ‘yes’, that there are restrictions to the integrating of sustainability in TE subjects. 35.7% of participants answered ‘no’.

Most of the concerns outlined by participants who answered ‘yes’ pointed to restrictions that centred around time constraints, costs constraints, CPD training and a lack of clarity in TE syllabi. Many teachers pointed to a crowded syllabi arguing that there is “already so much to incorporate in terms of literacy and numeracy” leaving little time for the incorporation of sustainability. Many participants also pointed to costs constraints such as the “initial costs of sustainable materials” and restrictive school budgets. Others pointed to a “lack of awareness and training” amongst colleagues and highlighting CPD as a means of keeping teachers up to date on cutting edge technologies and modern teaching on sustainability. The final theme amongst participant answers was a lack of cohesion among TE syllabi on the topic of sustainability. Participants frequently sighted the lack of a formal inclusion of this topic in TE syllabi leaving issues of sustainability “to be taught on an ad hoc basis.”

Participants who answered ‘no’ tended to frequently incorporate aspects of sustainability into their teaching with answers such as “I believe sustainability to be an integral part of the course and that this is where a lot of the strength of our subject lays. I like teaching about sustainability and do not think about restrictions hence I do not feel there are any.”

***Q6. Perception - Can you see any opportunities or benefits when it comes to integrating sustainability into technology subjects?***

The findings indicate that teachers overwhelmingly recognise the benefits of incorporating sustainability into their teaching, with 96.4% (135 respondents) answering ‘yes’ to this question. As such, despite 64.3% of participants identifying limitations to the incorporation of sustainability in the previous question, many simultaneously agree that there are also benefits to sustainability’s integration in TE subjects.

The vast majority of participants who answered ‘yes’ identified opportunities that related to societal awareness such as an “increase [in the] awareness of young people so they can contribute to sustainability”. Another commented that TE subjects provide a “great opportunity to change [the] mind set of [the] general public to one of sustainability - opportunity to normalize a society which works towards sustainability”. Participants also comment that;

“sustainability should be introduced to the students from a very early age. The students should learn to appreciate materials and where they come from. Teachers should lead by example and re-use materials to make furniture for the classroom and implement waste into students’ projects and designs.”

“sustainability is something that should be integrated into all subjects and all aspects of school. Promoting it in just a few subjects, or for just a few weeks in school turns it into just a novelty idea, rather than an idea for life.”

Such answers demonstrate the consensus among teachers of the scope for TE subjects to ESD, in particular in relation to cleaner production and consumption patterns of materials and products.

The majority of participants who answered ‘no’ outlined that they don’t see any opportunities to ESD within TE at the moment due the fact that “teachers [are] restricted to teaching to the exam and the mode of assessment in Irish education.”

Finally, participants were asked to briefly describe any suggestions or ideas as to how sustainability could be integrated into TE subjects. Similar to the results of question 2 above, the emerging theme amongst participant answers was one of material based ideas. For instance, participants comment that;

“integrating it [sustainability] into our technology class by running the machine building club that processes plastics into new products so they’re actively reusing the materials PET, HDPE and PVC. This will enable students to make money from rubbish”

“simple things like recycling of classroom waste on a continuous basis to show that sustainability is not just a one week gimmick in the school.”

Such answers demonstrate that teachers have suggestions and ideas as to how to integrate sustainability into TE subjects.

## **6. CONCLUSION**

The results of this study demonstrate that 93.6% of participants recognise the existence of climate change and global warming, thus providing an insight into their opinions and values on this topic. Additionally, 77.27% of participant answers indicated a consistent and in depth understanding of the concept of sustainability. However, this leaves a not so insignificant percentage of participants whose answers demonstrated only a surface level understanding of sustainability. Furthermore, 99.3% of teachers and trainee teachers surveyed recognised the importance of educating future generations about responsible consumption and production patterns. In addition, the findings indicate that teachers overwhelmingly recognise the benefits of incorporating sustainability into their teaching. Despite this, 64.3% of participants also recognised that there are restrictions to the integration of sustainability in TE subjects. The primary restrictions identified were time constraints, costs constraints, CPD training and a lack of clarity in TE syllabi.

In terms of teacher practice, while 81.2% of participants said that they teach about sustainability, the results highlight that in practice sustainability is incorporated into their teaching infrequently, with 40.6% indicating that they teach sustainable practices on a monthly basis. Similarly, when asked where in their teaching do they teach for sustainability the results demonstrate that few participants incorporate sustainability into multiple aspects of their teaching. The majority of respondents only identified one area within TE subjects such as, the design stage or the evaluation stage of projects. These findings highlight the need for further integration of sustainability into TE given the subject’s scope to drive social change towards a sustainable global future.

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# Using Engineering Design Challenges to Promote Imagination and Innovation in Integrative STEM Education

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Science, Technology, Engineering and Mathematics (STEM) education is a teaching and learning approach that has gained momentum around the world as nations try to stay competitive in the global economy. This paper provides a brief introduction to STEM education, followed by a review of integrated STEM education where a working definition is presented. Next, a discussion on developing engineering design challenges is presented followed by a discussion on how they promote imagination and innovation. The final section details how a quality integrated STEM education activity using an engineering design challenge approach might be developed.

*Key words: STEM Education, Integrated STEM Education, Engineering Design Process, Engineering Design Challenges*

## 1. INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) education is a teaching and learning approach that has gained momentum around the world as nations try to stay competitive in the global economy. Getting young people interested in STEM may lead to them choosing a career in a STEM-related field and this helps build a competitive STEM-educated workforce.

Learning about STEM in P-12 education is important, but what is the best way to develop and deliver STEM education curricula, including STEM education activities? This author believes the answer is through an integrated STEM education approach where activities are presented in engineering design challenges.

This paper begins with a brief introduction to the concept of STEM education, followed by a discussion on integrated STEM education where a working definition is presented. Next, a discussion on engineering design challenges, followed by a discussion on how engineering design challenges promote imagination and innovation. The last section details how a quality integrated STEM education activity using an engineering design challenge approach might be developed.

## 2. STEM EDUCATION

STEM education is at the forefront of many nations' educational agenda as they work to develop a STEM-educated workforce that competes in today's global economy. The U.S. Department of Education (n.d.) has noted the importance of STEM education in the U.S. and helping the U.S. to become a global leader and has stated the following:

In a world that's becoming increasingly complex, where success is driven not only by what you know, but by what you can do with what you know, it's more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information. These are the types of skills that students learn by studying science, technology, engineering, and math.

STEM has a daily impact on all of our lives. It is involved in the food we eat, the water we drink, the shelter we live in, and the transportation we use daily to take us places. STEM education is typically not a program or course, it is a teaching and learning approach in which the concepts and practices of STEM are integrated. It is

an approach that may improve student motivation learning and understanding as they holistically see the content or concepts coming together. It is also an approach that may help students become interested in pursuing a STEM-based career.

Those involved in STEM education need to have a basic understanding and context for the components of STEM. For purposes of this paper, a simple definition of the components of STEM are defined as follows:

- Science: Study of the Natural World
- Technology: Modifying the Natural World to Meet Human Needs and Wants
- Engineering: Applying Math and Science to Create Technology
- Mathematics: Numbers, Operations, Patterns, and Relationships

In the U.S., the idea of adding “arts” to STEM (to create STEAM) has been gaining momentum. Art is about creative expression and using imagination and skill to make something beautiful or something that expresses important ideas or feelings. This author agrees that art is important to STEM but believes it is already inherently involved in STEM. For example, in the real-world, solutions to engineering design problems often involve designers and artists who must develop objects to be aesthetically pleasing.

### 3. INTEGRATED STEM EDUCATION

Integrated or Integrative STEM education is about bringing together the STEM disciplines as it may improve student learning. Stohlman, Moore, and Roehrig (2012) agree that STEM education is one way to make learning more connected and relevant for students and note that “there is a need for further research and discussion on the knowledge, experiences, and background that teachers need to effectively teach integrated STEM education” (p. 28). Bybee in *The Case for STEM Education: Challenges and Opportunities* (NSTA 2013) argues that the “purpose of STEM education is to develop the content and practices that characterize the respective STEM disciplines” (p. 4).

There are many interpretations of the meaning of integrated (STEM) education. The concept of integration is about bringing together the parts of something into a whole or larger unit, and often integration is related to improving or making the situation more effective. For example, in a K-12 classroom successful “technology integration” would bring together instructional technology (e.g., computers, smartphones, software, the Internet, etc.) in a seamless manner where using it becomes second nature (Edutopia, 2007).

The International Technology and Engineering Educators Association (ITEEA) promotes the idea and importance of Integrative STEM Education (I-STEM). ITEEA (n.d.) operationally define Integrative STEM as:

“the application of technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels” (Wells & Ernst, 2012/2015). (As adapted from Wells/Sanders program documents 2006-10).

Kelley and Knowles (2016) noted efforts by Sanders (2009) and Moore, et al. (2014) to define integrated STEM education and after reviewing their ideas, they proposed to define integrated STEM education “as the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning” (p. 3).

In the National Academies publication, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research* (2014), they note the importance of “connections” among STEM subjects and discuss the how the concept of integrated STEM education occupies a multidimensional space in the larger K–12 education landscape (e.g., integrated STEM may occur in one or several class periods, or be reflected in the organization of a single course, or an entire school) (p. 31). In describing the nature of integrated STEM education, a framework was presented that identified four features that should be considered. These four features addressed

the (1) goals of integrated STEM education, (2) outcomes of integrated STEM education, (3) the nature and scope of integrated STEM education, and (4) implementation of integrated STEM education (p. 32).

In reviewing the previous literature on integrated STEM education, the author of this paper proposes defining integrated STEM education as follows:

Integrated STEM education is as an approach that purposely brings together common concepts, content, and practices of all the STEM disciplines into meaningful hands-on problem-solving activities to help students to better understand the subject matter being studied.

The proposed integrated STEM education definition is applicable at the K-12 level and promotes learning the concepts and content in each of the disciplines. A concept is a general idea about something. Concepts are a way of thinking in one's mind and are typically based on past experiences (e.g., the concepts related to hot and cold). A concept is broad in nature and may include thinking about the knowledge and skills related to the concept (e.g., the concept of driving a car requires both knowledge and skills).

Content refers to the topics or subjects covered in the STEM discipline area. Important concepts and content required in the STEM disciplines can be identified in current national/international standards developed for science, technology, and mathematics. These standards identify the knowledge and skills need to be literate in the STEM discipline and include the Standards for Technological Literacy: Content for the Study of Technology (ITEEA, 2000/2002/2007), the Next Generation Science Standards (n.d.), and the Common Core State Standards (CCSS, n.d.) for mathematics. There currently are no national standards for engineering.

In the definition presented for integrated STEM education in this paper, the common "practices" for science refers to the use of scientific inquiry. Scientific inquiry relates to how scientists study the natural world. It includes the approaches they use to develop knowledge and understanding of scientific ideas. A popular approach is the scientific method. The scientific method is used to answer questions about happenings in the natural world. There are many variations of the scientific method, but most are similar in nature and include the following steps:

- Make an observation and ask a question
- Develop a hypothesis or testable explanation related to question
- Develop an experiment to test the hypothesis
- Observe and collect data during the experiment
- Analyse the data and form a conclusion
- Share the results

For technology and engineering, the common practice would be the "engineering design process" (or engineering design). In K-12 education, the teaching of engineering design for many years has been an important focus in the subject area known as technology and engineering education (formerly technology education). The concepts of design and engineering design are strongly emphasized in the Standards for Technological Literacy: Content for the Study of Technology (2000/2003/2007). Lewis (2005) noted that "design is arguably the single most important content category set forth in the standards" (p. 37), and he championed that engineering design is the primary content area for technology education. In the Standards for Technological Literacy, engineering design is defined as:

The systematic and creative application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems. (ITEEA, 2000/2002/2007, p. 238).

The importance of students learning engineering design was further strengthened in The Next Generation Science Standards, NGSS (2013, Appendix I) that made a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels, from kindergarten to grade 12 (NGSS, 2013). In the NGSS, they note the term "engineering design" has replaced the older term "technological design," and the NGSS use recommendations from A Framework for K-12 Science Education (NRC, 2012) for the teaching of engineering

design. The NGSS do not refer to engineering design as a process or list a series of problem-solving steps. Rather, they encourage that students learn the core ideas of engineering design.

In the Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012), the committee recommend that science education in grades K-12 be built around three major dimensions, and one of these dimensions' focuses on the practices of science and engineering (p. 3). This paper and the proposed integrated STEM education definition supports this thinking and believes integrated STEM education must include both practices in an integrated STEM education activity. The practices of science and engineering presented in the framework are shown below.

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

For purposes of this paper, a simple six-step engineering design process proposed by NASA (n.d.) in their Beginning Engineering, Science, and Technology (BEST) program is used. This model was modified after the Engineering is Elementary (EiE) curriculum (Boston Museum of Science, n.d.). These steps support the practices of science and engineering presented in the Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (2012) and are listed and briefly discussed below.

1. ASK: Students identify the problem, requirements that must be met, and constraints that must be considered.
2. IMAGINE: Students brainstorm solutions and research ideas. They also identify what others have done.
3. PLAN: Students choose two to three of the best ideas from their brainstormed list and sketch possible designs, ultimately choosing a single design to prototype.
4. CREATE: Students build a working model, or prototype, that aligns with design requirements and that is within design constraints.
5. TEST: Students evaluate the solution through testing; they collect and analyze data; they summarize strengths and weaknesses of their design that were revealed during testing.
6. IMPROVE: Based on the results of their tests, students make improvements on their design. They also identify changes they will make and justify their revisions.

In mathematics, common practices for integrated STEM education would always emphasize basic math concepts (e.g., those learned in the early years of schooling such as measuring, addition, subtraction, multiplication, division, data, and geometry). Furthermore, the use of math in STEM should be guided by "grade appropriate" mathematical concepts outlined in the Common Core State Standards (CCSA, n.d.).

#### **4. ENGINEERING DESIGN CHALLENGES**

One method of developing motivating and real-world integrated STEM education activities and experiences can be achieved by using "engineering design challenges." Householder and Hailey (2012) note that "engineering design challenges are ill-structured problems that may be approached and resolved using strategies and approaches commonly considered to be engineering practices" (p. 2).

Engineering design challenges require students to solve real-world problems and this promotes imagination, innovation, and 21st century skills that include communication, coloration, critical thinking and creativity (P21, 2007). Engineering design challenges also promote students applying the engineering design process, using scientific inquiry, and integrated STEM education.

There is no set format on how to present an engineering design challenge and can be as simple as asking students to solve an engineering type problem (e.g., develop an automatic pet feeder). However, this author has found it helpful to include more details in an engineering design challenge and recommends that engineering design challenges be framed using the following components:

- (ii) Situation: Sets a real-world context for the problem.
- (iii) Challenge: States the problem to be solved.
- (iv) Criteria and Constraints: Criteria are those things (e.g., must be able to hold  $\frac{1}{2}$  pound or 227 grams) that must be followed or satisfied when completing the challenge. Constraints are typically limits (e.g., the structure must be built in 20 minutes) related to the challenge.
- (v) Resources: Identifies the materials, tools, or equipment that are provided or can be used to help solve the problem.
- (vi) Evaluation: Describes how the solution to the problem will be assessed and evaluated.

In addition to the above sections, an engineering design challenge can include “references” related to the problem that students can use to investigate the problem further. In addition, this author recommends that both the customary system of measurement (used in the U.S.) and the metric system or SI (International System of Units) be used in engineering design challenges. Using both measurement systems promotes students learning multiple systems of measurement that are used in many contexts.

## **5. ENGINEERING DESIGN CHALLENGES PROMOTE IMAGINATION AND INNOVATION**

Engineering design challenges promote imagination, innovation, and creativity as they require students to solve open-ended real-world problems. Imagination is using one’s mind “to see” the impossible or unreal. It is also about the ability to confront and deal with a problem (e.g., use your imagination to find a solution to the problem). Innovation is related to improving existing products, processes or systems. It also relates to developing new ideas, methods, and products. Often used with the term innovation is “invention” which relates to developing something new that has never existed before.

In an engineering design challenge, students use imagination and innovation to solve problems. Imagination and innovation require creativity. Creativity is a term with many interpretations often depending on the situation or context where it is being used. In solving problems in an engineering design challenge, an instructor may tell students to “think outside the box.” But what does this mean? In the context of solving an engineering design challenge, it means using creativity to come up with a new, novel, or innovative ways to do something (e.g., replacing strings to tie shoes with Velcro fasteners). It means being imaginative and original. It is this characteristic that often is easy to recognize. For example, when we see something creative for the first time (e.g., the touchscreen, or a sensor that opens a door) we know it. Also, for many of us, when we see simple creative ideas in use, we often think, I wonder who invented it, or I wish I would have come up with that idea.

Closely related to creativity is innovation as they often go hand-in-hand. An innovation is an improvement of an existing technological product, system, or method of doing something (e.g., today’s smartphone is an innovation of the original “large and heavy” mobile phone). It uses “novel and creative ways” to create new products and services that people want and need and can be thought of as a “creative problem-solving method” (Wagner, 2012). Wagner (2012) encourages schools to teach innovation based on collaboration as they believe that education needs to teach young people to become innovators who may someday change that world and argues that our country and our planet need innovators in order to thrive in the 21st century.

## **5. DEVELOPING INTEGRATED STEM EDUCATION ACTIVITIES**

What does an integrated STEM education activity look like? There are many interpretations (e.g., Kelley and Knowles, 2016; Vasquez, 2013). This paper recommends that a well-developed and quality integrated STEM education activity presents students with an engineering design challenge that requires them to use both the engineering design process and application of a scientific inquiry approach in solving a real-world problem. In presenting the activity, the instructor would intentionally address concepts and content from each of the STEM disciplines. The activity would be “standards-based” and student-centered. It would be completed in a small group setting using “real tools, materials, and equipment” when possible and include both formative and



summative assessment measures. It would also show STEM career connections, have a literacy aspect and if applicable, provide global perspectives related to challenge or problem.

Shown below is an example of “selected components” from an integrated STEM education activity entitled Lighted Transmission Tower. In this integrated STEM education activity, concepts, content, and practices of STEM are purposely integrated as students use their imagination to build a lighted transmission tower.

#### Engineering Design Challenge (Practice in Engineering)

*Context (Situation/Problem):* A small airport is being built in a remote village in Africa and the best location has been selected based on terrain and access. However, near the proposed airport site are large electrical transmission towers that are used to supply power around the region. To improve safety, it has been suggested that “lighted transmission towers” be built.

*Challenge:* In this activity, small engineering teams will use the engineering design process as the team builds a small-scale prototype of a lighted transmission tower.

#### Experiment: Brightest Glow Stick (Practice in Science)

*Context (Situation/Problem):* A small airport is being built in a remote village in Africa and the best location has been selected based on terrain and access. However, near the proposed airport site are large electrical transmission towers that are used to supply power around the region. To improve safety, it has been suggested that “lighted transmission towers” be built. To be as safe as possible, the engineers want to use what people perceive are the brightest lights.

*Scientific Question:* Given a set of different colored glow lights, set up an experiment to measure what glow stick people perceive to be the brightest.

#### Concepts, Content, & Practices in STEM Worksheet (Questions)

<i>Science:</i>	What is inside a glow stick?
<i>Technology:</i>	What are glow sticks used for?
<i>Engineering:</i>	Actual transmission towers are often built using trusses. What is a truss?
<i>Mathematics:</i>	Name two different math operations that were used in the building of the lighted transmission tower.

## 6. CONCLUSION

Engineering design challenges are a method that can be used to present integrated STEM education activities. Well thought out engineering design challenges require students to solve real-world problems. Solutions to these problems promote students to use imagination, innovation, and creativity. Activities and lessons that focus on engineering design challenges also promote student motivation and STEM integration where students learn about the concepts, content, and practices of STEM.

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# Scientific and Technological Processes in K-12 classrooms in Quebec Schools: Common Features and Differences

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The latest Quebec Education Reform integrates technology education and science education into the same discipline called Science and technology. This integration causes the major challenges for teachers who are not trained in both technology education and science one. In this article, we will present the scientific and technological practices from teacher perspectives. To do so, we will firstly elaborate on the specific circumstance of science and technology education in Quebec school system. Secondly, we will analyze how teachers understand these processes and what they see as commonalities and differences between them. To gain insight into the teachers understanding, we asked them to describe two teaching situations recently implemented in their classrooms and to compare the common elements, as well as the differences between the technological process and the scientific inquiry. The data collected from this step will help us to understand the various approaches that characterize teaching practices in Quebec middle Schools. For the second purpose, we reminded teachers that the curriculum advocates the scientific inquiry for science and the technology design process for technology, and then we asked them to illustrate, based on some examples, what they perceive as differences and commonalities between these two processes. The outcomes show that about 50 % of respondents consider that the two processes are similar in their steps. Regarding the differences, the respondents indicate that the two processes are similar except with respect to their purpose and their final product. Based on these various results of the survey, we will discuss the impact of the teachers understanding of these processes on the student's learning. Moreover, we will get insights into the challenges that can face the integration of STEM education in the Quebec School system. Finally, the outcomes could help the stakeholders to think about not only the major challenges facing the education of the new generations of citizens but also preparing staff development, which includes both initial teacher education and continuing professional development.

*Key Words: Science inquiry, Technology design process, Engineering design process, STEM education.*

## 1. INTRODUCTION

The Quebec Education Program (2004), in middle school, creates a single discipline by integrating five scientific fields (astronomy, biology, chemistry, geology, physics) and technology. Furthermore, the Program adopts the competency-based approach and aims to develop a basic scientific and technological literacy for all students (El Fadil, Hasni and Lebeaume, 2017).

- The Quebec Program focuses on the development of the followed three competencies:
- Seeks answers or solutions to scientific or technological problems (Competency 1)
- Makes the most of his/her knowledge of science and technology (Competency 2)
- Communicates in the languages used in science and technology (Competency 3)

In these circumstances, the role of teachers is essential. The competency-based approach requires that teachers must be familiar to the art of teaching as well as their subject area. They must also demonstrate creativity and professional judgment. They are responsible for developing learning and evaluation situations that foster

competency development, adjusting their teaching practices so to ensure educational differentiation and choosing the teaching strategies most likely to meet students' needs.

In order to help students develop Competency 1, "Seeks answers or solutions to scientific or technological problems", the Program stated that teachers should propose learning situations that encourage students to adopt a problem-solving approach involving the experimental method or the design process. These situations require a hands-on approach. They may also involve modeling or the observation or empirical method.

Once again, these requirements highlight the persistent challenges that arise from teachers' lack of training in the field of technology education. Indeed, many studies, conducted in the Quebec context, show that while teachers are tasked with the responsibility of providing the learning opportunities for their students, many are not trained to take on this challenge (El Fadil, 2016; El Fadil, Hasni and Lebeaume, 2017; Hasni, Lenoir and Froelich, 2015).

These changes present opportunities, as well as concerns, for most of educators. Likewise, as the science and technology discipline is a relatively new field, there is limited research, in Quebec context, examining the efficacy of this integration.

## 2. LITERATURE REVIEW

A large study conducted by Potvin and Hasni (2014) offers a synthetic and systematic description of 228 research articles that were published between 2000 and 2012 under interest for science and technology at K-12 levels. Their study shows that four teaching and learning approaches that have positive effects on motivation, are identified as quantitatively predominant: 1) problem-based learning, which includes the Technology Design Process (TDP) and the Scientific Inquiry (SI), 2) integration of the Information and Communications Technology (ICT), 3) Collaborative work, and 4) Contextualization.

In this paper, we have limited our analysis to the first approach, problem-based learning, because it touches upon both of technology and science education. However, as stated by Laughlin, Zastavker and Ong (2007), effectively capitalizing on the similarities and differences in discipline-specific modes of thinking is one of the challenges to a fully integrated science and technology education. TDP and SI based learning are two modes of thinking that are critical to engineering/technology and science respectively. They provide a common fertile learning environment between these disciplines from primary level to high school level.

In this perspective, Bybee (2011) underlines that even before elementary school, children ask questions of each other and of adults about things around them, including the natural and designed world. Consequently, if students develop knowledge about the TDP and SI, they can ask better questions and improve how they define problems.

It is worth remembering that one of the education purposes is to help student to think and to ask good questions. Students should, for example, learn how to ask good questions of each other, to recognize the difference between questions and problems, and to evaluate scientific questions and technological problems from other types of questions (Ibid.).

In upper grades (elementary level), the practices of asking scientific questions and defining technological problems advance in subtle ways such as the form and function of data used in answering questions and the criteria and constraints applied to solving problems.

In the lower grades (upper level in elementary school and first cycle in middle school), the idea of scientific and technological models can be introduced by using pictures, diagrams, drawings, and simple physical models such as simple machines and components of a system. In upper grades (second cycle in middle school), simulations and more sophisticated conceptual, mathematical, and computational models may be used to conduct investigations, explore changes in system components, and generate data that can be used in formulating scientific explanations or in proposing technological solutions. To achieve this end, the engineering concepts such as motion transmission and motion transformation system could be used. Across the grades, students develop deeper understandings and abilities as they carry out different types of investigations, use ICT

to collect data, pay special attention to the types of variables that can affect the problem, and clarify the scientific or engineering contexts for investigations. This kind of practices along with using mathematical and computational thinking is significant, because it gives the opportunity to students to experience the practices of collecting, analyzing, and interpreting data and in the process apply mathematical thinking (Bybee, 2011). In the early grades, students can learn to use appropriate tools and instruments (e.g., scales, thermometers and graduated cylinder) and their units in measurements and in quantitative results to compare suggested solutions to a technological problem. In upper grades, students can use machine tools and soldering iron to make artefacts and computers to analyze data sets and express the significance of data using mathematics (statistics). They can also learn to use computers to record measurements, summarize and display data, and calculate relationships.

The purposiveness of Education Program is to help all grade levels' students to learn how to use evidence to formulate a logically coherent explanation of phenomena in science and to support a proposed solution for a technological problem in technology and engineering. The construction of a scientific explanation or a technological solution should incorporate current scientific and technological knowledge and often include a model. To do so, students must understand both the SI and the TDP.

## ***2.1 TDP and SI - similarities and differences***

### *2.1.1. The SI*

According to Hasni, Roy & Dumais (2016), the SI, in a specific way, refers to two aspects: a) a scientific process that students must understand; and b) a teaching and learning process in relation to the acquisition of scientific knowledge.

With regard to the SI that students must understand, let us mention one of the best-known processes that influenced Quebec school system. It is Claude Bernard's (1813-1878) approach (Johsua et Dupin, 1993), which shifted the emphasis from students' memorizing six steps in the scientific method to their learning specific and fundamental processes (Hasni and Potvin, 2015) such as observing, hypothesizing, clarifying, measuring or experimenting, inferring, and predicting.

However, many educators have criticized this approach because it reduces the SI to a single stereotypical model and assumes that phenomena can be observed in a neutral and linear manner.

As part of this approach, classroom scientific experiments or labs often do not rise to the level of SI since there is usually an explicit focus on memorizing and verifying established knowledge through established linear procedures (Hanauer et al., 2006; Hasni, Roy and Dumais, 2016)

Subsequently, during the period 1960–1990, interest and support grew for SI as an approach to science teaching that emphasized learning science concepts and using the skills and abilities of inquiry to learn those concepts (Bybee, 2011). It is important to note that that shift in the process of science learning has provided a richer understanding of science, a set of cognitive abilities for students, and more effective teaching strategies. However, SI as a form of scientific practice has not been implemented as widely as expected.

Actually implementing SI in education requires giving students opportunities for ideation (with some guidance) and redesign of experiments without exclusively focusing on attaining the correct result (Johns and Mentzer, 2016).

Likewise, focusing on generating new knowledge through hands-on approach, instead of correct results, does not mean that those correct results are not important for students' understanding of the subject content. The distinction here is that knowledge of the science content and knowledge of how to carry out SI are not the same. Inquiry skills are not learned just because science content is taught (Williams et al. 2007). Developing SI skills requires not just the opportunity to engage in inquiry but also to have the freedom to try different processes and gain understanding of how to learn knowledge from inquiry.

### *2.1.2. The TDP*

According to ITEA (2007), the TDP includes defining a problem, brainstorming, researching and generating ideas, identifying criteria and specifying constraints, exploring possibilities, selecting an approach, developing a design proposal, making a model or prototype, testing and evaluating the design using specifications, refining the design, creating or making it, and communicating processes and results.

Taken as a whole and objectively read, we can summarize the TDP process in three following steps: (1) the identification the problem, trade-offs and constraints, (2) the ideation of potential solutions, and (3) the identification of a solution to pursue based on evaluation of the trade-offs and constraints (Johns and Mentzer, 2016). If the situation initiating any scientific inquiry (SI) is a problem or a question about a natural phenomenon, the one initiating any TDP is a human need, the technological problem. So, from the beginning of the design process, functional specifications and initial constraints are specified by some sort of needs analysis process (Jonassen, 2011). Likewise, trade-offs and constraints can be analyzed in terms of traditional measures such as cost, time to implement, etc. However, in tasks where science is integrated with technology these trade-offs and constraints are tied to scientifically examinable phenomenon. This kind of tasks offers an opportunity for students not only to analyze these dimensions based on experimentation, but also to experiment the technologist and engineering practices.

TDP is the process that engineers use to discover knowledge-based solutions to open-ended problems by using knowledge acquired from literature and experiences. Teachers should emphasize on conceptual knowledge while solving problems in their classrooms. As Brand, Kasarda, and Bryant Williams (2017) stressed that without taking into account conceptual knowledge encourages Band-Aid or ad hoc solutions without a clear understanding of content-based explanations.

### *2.1.3. The Differences and similarities*

According to many recent studies, there is evidence that technology and engineering in K-12 classrooms would give an opportunity not only to engage with science content in an applied context (which is expected to have positive motivational effect), but also to introduce students to the fields of technology and engineering (Hasni and Potvin, 2014; the National Academies of Engineering and National Research Council, 2009). Moreover, Wicklein (2006) argues that technology education focus on technology or engineering design process provides an ideal platform for integrating mathematics, science, and technology. Furthermore, acknowledging the differences in these three modes can help both teachers and students to clarify the kinds of problems and questions that could be provided to students (Johns & Mentzer, 2016).

Examining the similarities will provide opportunities to bridge a gap between these modes of thinking and facilitate the integration of engineering, technology and science content of a task (Eekels & Roozenburg, 1991). The integration of knowledge and processes is supported by many researches in education (Conseil Supérieur de l'Éducation, 2013; Hasni, Lenoir & Froelich, 2015; ITEA, 2007). It is considered not only as the foundation for problem solving and innovation, also as an integral part of the practices of engineers and scientists. Engineers create and develop solutions by applying the fundamentals of science, mathematics, and technology. Through SI and TDP, students discover and learn theories and principles. From these learning, they develop knowledge that is used to understand relationships to other concepts or systems and to design testable models that lead to new solutions.

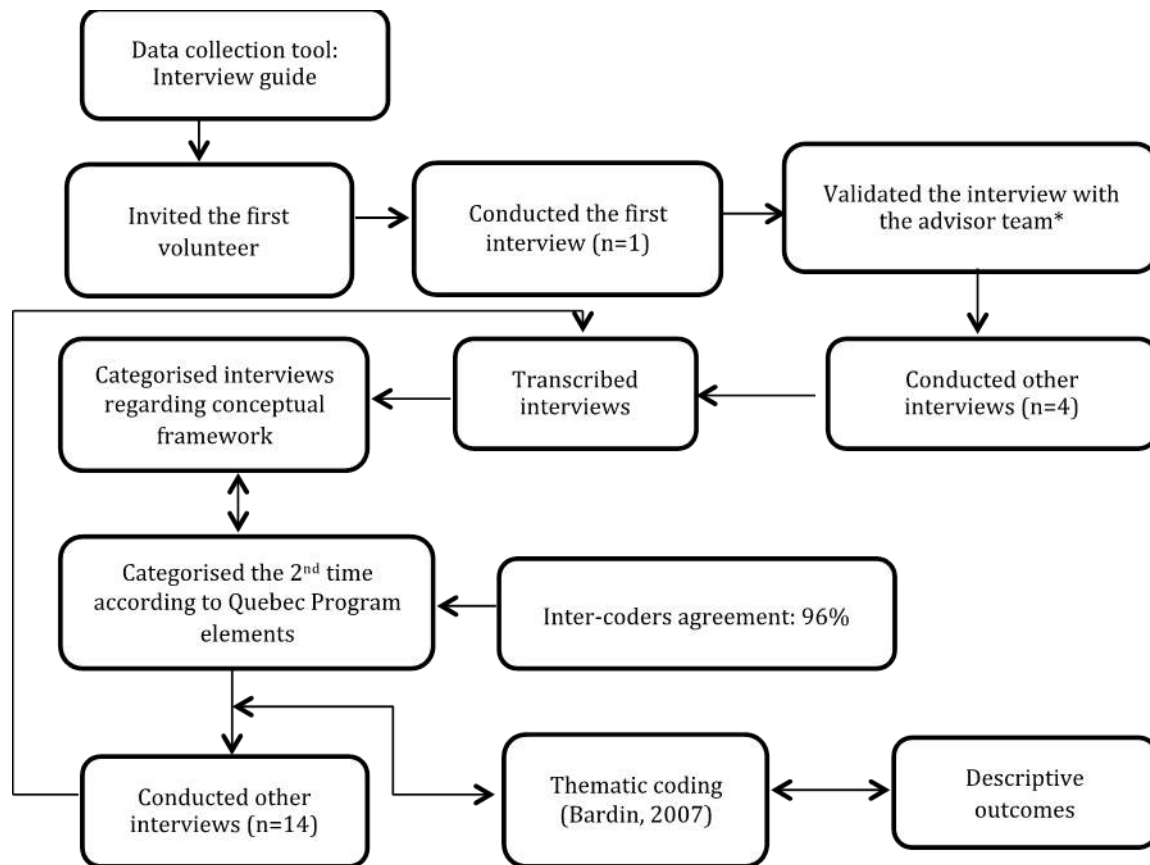
## **3 METHOD**

The data analyzed here is based on the work we carried out in the framework of our doctoral research. This study examined the degree to which science and technology teachers were understand the TDP and the SI and how they implement them in their classrooms.

Although the integration of STEM knowledge is supported by research, we have focused our study on technological and scientific practices, as they fit well with Quebec Education context (integration of science and technology).

Nineteen participants were selected (convenience sampling) and interviewed. During the interview, we reminded teachers that the curriculum advocates the SI for science and the TDP for technology, and then we

asked them to illustrate, based on some examples, what they perceive as differences and commonalities between these two processes. All interviews were recorded, transcribed verbatim, coded and analyzed based on the techniques of thematic categorization (Bardin, 2007) as shown in figure 1.



\* The advisor team consists of three professors (Two from University of Sherbrooke, Canada (1 from Faculty of Education and 1 from Faculty of Engineering), one from University of Paris-Descartes, France)

Figure 1. The process of gathering data and analysing.

#### 4 RESULTS

All respondents stated that the TDP and the SI had several similarities (some steps such as making, using tools, materials and collecting data) and relied on scientific and mathematical knowledge.

Regarding differences, most respondents distinguished them by their purposes. The aim of the TDP was to respond to the human needs or solve technological problems while the SI pointed to answer a question or test a scientific hypothesis.

With respect to the use of resources for research and information, four respondents mentioned that feature. They claimed that in the TDP, the use of resources for research was completed early in the process, while in SI, if conducted, it was done at the end, after collecting data.

In connection with the iteration, four teachers indicated that the TDP is iterative, which allowed optimizing the conceived solution; whereas the SI is rigid (not iterative), as illustrated by the following extract.

*The SI is rigorous. It follows the specific steps. And you cannot move from one step to another if you have not succeeded the previous one. While in the TDP, there is no absolute rigor. There is creativity while respecting the steps. I could not call it an investigation but a creation. (R1)*

Two respondents also identified the number of possible solutions as a difference between the two processes. According to them, several solutions are possible when using the TDP, while in SI, there is only one possible solution, as shown in the excerpt below.

*In scientific practices, we never consider several possible solutions. We just ask students to formulate a single hypothesis and not several. However, in technology practice, we ask them to suggest several possibilities. So, that is one of the differences. (R 2)*

As for the assessment of students' learning, two respondents thought that in TDP, the assessment was conducted throughout the learning process (formative assessment); while in SI, the assessment was rarely conducted during the process, but only at its end (summative evaluation).

About the final product of the two processes, eleven respondents considered that the TDP led to the manufacturing of an artefact, while the SI ended with a laboratory report or, at the upper limit, a scientific article.

To wrap up, here is, in Figure 2, an overall picture of teachers' considerations.

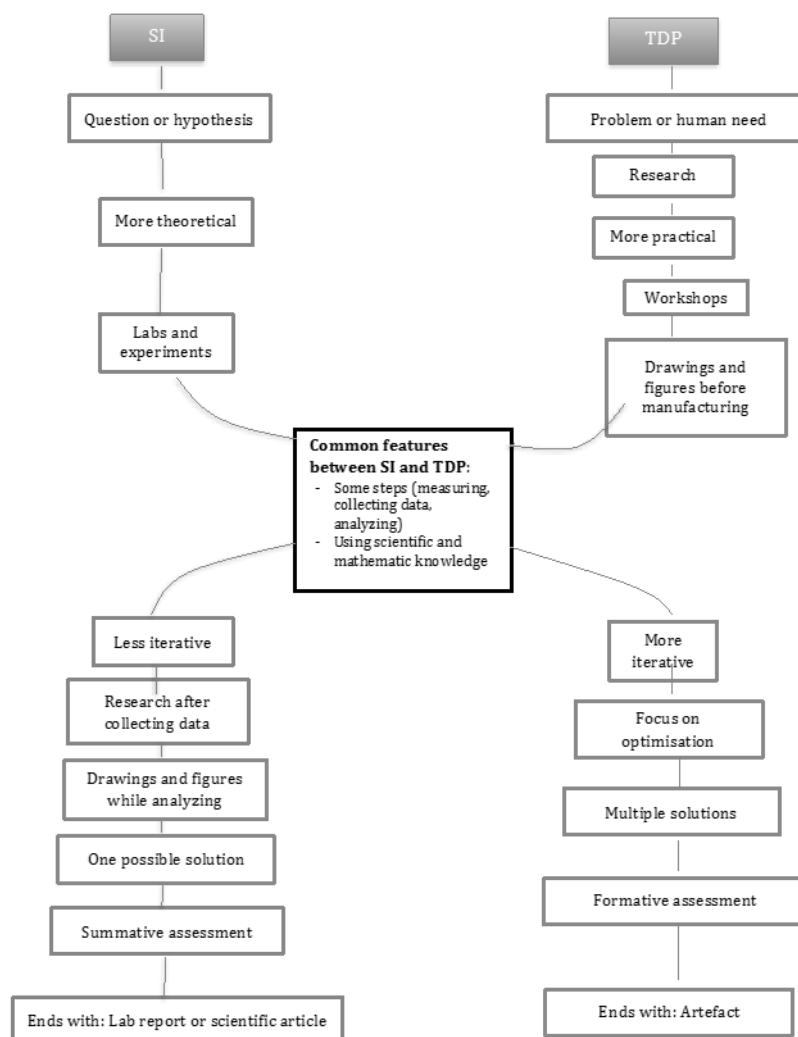


Figure 2. Schematisation of teachers' answers as a whole.



## 5 DISCUSSION AND CONCLUSION

The results of the study highlight that teachers have different understandings of the TDP and the SI, which leads to a variety of ways of implementing these processes.

Accordingly, it seems reasonable to note that in the context of Quebec Education, where science and technology are integrated into the same discipline, it is very important, for learning, to distinguish between science and technology especially between their specific processes and knowledge. In the same optic, Bybee (2011) distinguishes between the two processes. He argues that SI begins with a question about a phenomenon such as “how rainbows are formed?” or “What causes cancer?” A basic practice of the scientist is the ability to formulate empirically answerable questions about phenomena to establish what is already known, and to determine what questions have yet to be satisfactorily answered. He also claims TDP begins with a problem that needs to be solved, such as “how can we clearly observe the stars? Or “How can we improve the fuel efficiency of automobiles? A basic practice of engineers and technologists is to ask questions to clarify the problem, determine criteria for a successful solution, and identify constraints.

Nevertheless, this use of already known knowledge and available resources did not emerge in the interviews.

Another point that was neglected by the respondents was the engagement of students in scientific argumentation and reasoning while investigating. Indeed, in SI, reasoning is essential for clarifying strengths and weaknesses for finding the best explanation for a natural phenomenon. In SI, scientists must support their explanations, formulate evidence based on a solid foundation of data, examine their understanding in light of the evidence, and collaborate with peers in searching for the best explanation for the phenomena being investigated (Idem).

In TDP, reasoning and argument are essential for finding the best solution to a problem. Technologists and engineers collaborate with their peers throughout the design process. In this perspective, during the process, students must identify several possible solutions. According to Bybee (2011), one of the critical stages through the TDP is the selection of the most promising solution among a field of competing ideas. Technologists use systematic methods to compare alternatives, formulate evidence based on test data, make arguments to defend their conclusions, critically evaluate the ideas of others, and revise their designs in order to identify the best solution. These features highlight the iteration, which is one of the specific characteristics of the TDP but often neglected by teachers.

Moreover, respondents often failed to point out that communication is a common feature between the TDP and the SI. As a matter of fact, science and technology cannot advance if scientists and technologists are unable to communicate their findings clearly and persuasively or learn about the findings of others. In their practice, scientists spend a lot of time of their work to communicate ideas and the results of studies with the use of scientific language (tables, diagrams, graphs and equations). In TDP, technologists cannot produce new artefact if the advantages of their designs are not communicated clearly and persuasively. Moreover, like scientists, technologists need to be able to derive meaning from other texts, evaluate information, and apply it usefully.

### ***5.1 The impact of implementing the two processes***

Our survey didn't aim as direct objective to study the impact of the two processes on students' learning. However, a large study completed by Potvin & Hasni (2017), in the same Quebec context as our study, examined the impact of investigative approaches on student interest in science and technology.

Their study summarizes the results of other studies that focused on the impact of implementing the two processes on students' learning. Subsequently, their review of articles, which investigated the links between affective constructs and inquiry-based teaching methods, shows that most of these articles reported positive outcomes and that none of the articles recorded negative results.

We should point out that even though many studies show the positive effects on learning, the process faces many issues. In accordance with Potvin and Hasni (2014) study, the first type of challenge to successful implementation is the understanding that teachers have of inquiry-based learning and its possible effects on

students. In this light, El Fadil, Hasni and Lebeaume (2017) declare that most teachers in Quebec middle schools present to their students the TDP as a sequential process, “Puzzle problem”, while it is actually a non-linear process that involves multiple retroactive loops and constant adjustments. But if teachers have never fully experienced this iterative method themselves, it is possible that they think it is a “recipe-like” of verification of previously presented knowledge (Potvin and Hasni, 2014). This drift often happens to teachers who do not have rigorous training in science and technology. In this perspective, Harris & Rooks assert that teachers can be challenged in enacting authentic science tasks if they are not familiar with the practices of scientists and have never participated in authentic scientific activity themselves.

The second type of challenge is linked to curricular considerations and to classroom management, which becomes more difficult with inquiry-based teaching. In this perspective, several studies confirm that learning through inquiry methods offers a very different way of learning for students, for it places higher demands on students in terms of participation, personal responsibility for learning, and intellectual effort. This process of learning changes the planning of teaching and interactions with students. Consequently, it requires a high level of pedagogical content knowledge, including a broad understanding of the nature of science and technology and the complexities of teaching, mentoring and collaborating. This approach assumes that interactions between teachers and students should be more open and less guided than in ordinary settings as Daker and Dow (2008) testimony. In the ordinary settings, the emphasis is on the development of procedural and declarative knowledge development. Each student is encouraged to follow exact processes as indicated by the teacher. When in difficulty or when a required more complex skill process, it is the teacher or Lab technician (expert) who demonstrates. However, teaching experiences show that the step-by-step procedure may not directly translate to success in inquiry classrooms.

Obviously, the results on the impact of the inquiry-based teaching developed above are about motivation and interest, but we assume that motivation, attitude and interest are closely related to learning outcomes as stressed by many authors (Cavas, 2011; Potvin and Hasni 2014; Reid & Skryabina, 2002; Singh, Granville, & Dika, 2002).

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# Outline of Workshops

Date: Tuesday 19th June (15:20 – 16:50)

## **WORKSHOP 1 - SPATIAL SKILLS WORKSHOP – Z103**

Dr. Sheryl Sorby has a well-established research program in spatial visualization, specifically in developing a curriculum to help students develop their spatial skills. She received her first grant from the National Science Foundation in 1993 to develop a course and course materials for helping engineering students to develop their 3-D spatial skills and has received numerous follow-up grants from the NSF and IES to further her work in developing and assessing spatial skills. Her spatial skills curriculum has been adopted by nearly 30 engineering programs across the U. S. In 2005 she received the Betty Vetter award for Research on Women in Engineering through the Women in Engineering Program Advocates Network (WEPAN) for her work in improving the 3-D spatial skills of (women) engineering students.

At the end of this workshop/tutorial, participants will be able to:

- Describe relevant findings regarding the impact of spatial skills training on STEM performance.
- Summarize key educational strategies that appear to develop spatial skills in students.
- Complete various exercises from the Sorby spatial visualization curriculum.

Timeline of the workshop:

0-40 minutes	Presentation (with questions) regarding a) the curriculum and b) key findings from Sorby's research relative to the impact of curriculum implementation.
40-80 minutes	Module 3 - Isometric Sketching and Coded Plans
80-90 minutes	General discussion and wrap-up regarding implementing the curriculum in the classroom

## **WORKSHOP 2 - IMMERSIVE TECHNOLOGIES WORKSHOP – X206**

Dr. Niall Murray is founder and PI of the tIIMEx (truly Immersive and Interactive Multimedia Experiences) research lab at Athlone Institute of Technology. This team of researchers develop and evaluate user Quality of Experience of Immersive Augmented and Virtual Reality applications across a range of application domains including digital heritage & tourism, education, health and smart manufacturing. In addition, it works with multisensory media (olfaction, haptic, etc.) as well as wearable sensor systems. The focus of this workshop is to introduce these immersive experiences to the attendees and solicit, through break out format, applications and project ideas on how this technology can be applied within educational settings.

At the end of this workshop/tutorial participants will be able to:

- Discuss the applicability of Immersive Multimedia Experiences in education.
- Summarize key opportunities and pedagogical implications of immersive technologies.

Timeline of the workshop:

0-25 minutes	Introduction to AR, VR and QOE
25-45 minutes	Demo and Discussion

### **WORKSHOP 3 – ADDITIVE MANUFACTURING WORKSHOP – V109**

Dr. Sean Lyons has a background in applied research using polymer materials working with automotive, medical and aerospace companies on new product and new process introduction. Sean is currently the acting Dean of Engineering at AIT and prior to that held positions in academia and industry leading Research & Development teams. The focus of the workshop is to discuss traditional manufacturing approaches for advanced materials, comparing and contrasting these approaches with emerging additive manufacturing technologies.

At the end of this workshop/tutorial, participants will be able to:

- Differentiate between various additive manufacturing techniques
- Understand the Pros and Cons of utilizing additive manufacturing techniques compared to traditional manufacturing technologies
- Develop fundamental experimental techniques using low cost Additive manufacturing technologies to promote interactive curricula development.

Timeline of the workshop:

0-15 minutes	Overview and Tour of various traditional high volume manufacturing technologies
20-35 minutes	Overview and demonstration of Additive manufacturing technologies
35-45 minutes	General discussion and wrap-up regarding utilizing AM processes in the classroom

### **WORKSHOP 4 - APP DEVELOPMENT WORKSHOP – X207**

Dr. Enda Fallon is a senior lecturer in software engineering at Athlone Institute of Technology (AIT). Having joined AIT from Ericsson in 2002 he founded AIT's Software Research Institute(SRI). Since 2002, Enda has been a principal investigator on over 70 collaborative industry/academic research projects. This workshop illustrates how elements of the Aalborg Model, problem-oriented and project-based learning paradigm can be applied in the development of a real world mobile app to enhance the potential for student critical thinking. Participants will be challenged to address a "real world" issue and to use the capabilities of MIT's online "App Inventor" application to brainstorm, create and deploy a mobile app from scratch to an Android Mobile Phone in 90 MINUTES. No previous technical knowledge is required!

At the end of this workshop, participants will be able to:

Describe issues experienced by users in a real world scenario  
Create a user interface design for an Android Mobile App  
Create the underlying functionality for the Mobile App  
Deploy the App to an Android Mobile Phone

Timeline of the workshop:

0-10 minutes	Background/Context/Introductions
10-20 minutes	Presentation of real world problem/Challenges/Technical Capabilities
20-50 minutes	Creation of App using MIT App Inventor
50-60 minutes	Re-visiting the problem
60-80 minutes	App enhancements/Deployments
80-90 minutes	Evaluation and Reflection

## CONFERENCE SCHEDULE

### Monday 18<sup>th</sup> June

**8:00 - 8:10**      **Travel via bus to AIT**

**8:10 - 9:00**      **Registration**

**9:00 - 9:15**      **Conference Opening:**  
Registrar and President AIT

**9:15 - 9:30**      **Keynote:**  
Minister for Higher Education- Minister Mary Mitchell O'Connor

**9:30 - 10:00**      Welcome and Schedule:  
Dr. Niall Seery and Prof. Marc J. de Vries

**10:00 - 10:30**      **Break and Refreshments**

**Parallel Sessions**  
**10:30 - 12:10**

**Session 1:**  
**X103 Engineering Building**

**Session 2:**  
**Y103 Engineering Building**

**10:30 – 10:55**      Rethinking Pupil's Attitudes Towards Technology  
(PATT) Studies  
**Piet Ankwicz**  
(pg. 1 - 8)

Technology teachers' different ways of thinking about sustainable development in technology education  
**Maria Svensson and Anne-Marie van Otter**  
(pg. 33 - 39)

**10:55 – 11:20**      Woman's under-representation in STEM: The part  
role-models have played in the past and do we still  
need them today?  
**Stephanie Atkinson**  
(pg. 9 - 15)

What technology content and values emerge in the  
teaching of climate change?  
**Susanne Engström**  
(pg. 40 - 46)

**11:20 – 11:45**      Changing Competencies, Changing Attitudes? How  
Teachers Become Technology Teachers  
**Brigit Fahrman, Per Norström and Lena  
Gumaelius**  
(pg. 16 - 22)

Technological thinking by children with special needs  
**Michal Levi and David Mioduser**  
(pg. 47 - 58)

**11:45 – 12:10**      A Global Analysis of how High School Activities are  
Preparing Students for the 21st Century  
**P. Scott Bevins Virginia Jones and Daniel L. Trent**  
(pg. 23 - 32)

Mitcham's Fourth: a case for foregrounding volition  
when framing Design and Technology Education  
**Steve Keirl**  
(pg. 59 - 64)

**Parallel Sessions**  
**12:10 - 13:25**

**Session 3:**  
**X103 Engineering Building**

**Session 4:**  
**Y103 Engineering Building**

**12:10 – 12:35**      Using linkography to explore novice designers' design  
choices during a STEM task  
**Nicolaas Blom, Grietje Haupt and Alfred Bogaers**  
(pg. 65 - 70)

Kindergarten programming goes mobile  
**Asi Kuperman, Ruthi Aladjem and David  
Mioduser**  
(pg. 81 - 87)

**12:35 – 13:00**      Conceptualisation Processes and Making  
**Antti Pirhonen**  
(pg. 71 - 75)

Learning science and technology from play in early  
childhood education  
**Hanno van Keulen and Mariska Venema**  
(pg. 88 - 95)

**13:00 – 13:25**      The Delft research programme on design for concept  
learning  
**Marc J. de Vries**  
(pg. 76 - 80)

STEM in Northern Ireland Primary Schools: Where is it  
at, and where should it go?  
**Kieran McGeown and Michael Ievers**  
(pg. 96 - 102)

13:25 - 14:15	<b>Lunch</b>	
<b>Parallel Sessions</b> 14:25 - 15:40	<b>Session 5:</b> <b>X103 Engineering Building</b>	<b>Session 6:</b> <b>Y103 Engineering Building</b>
14:25 - 14:50	STEM Associational Fluency: The Cross-Training of Elementary and Middle Grade Math, Science, and Engineering Pre-Service Teachers <b>Elizabeth Deurmeyer and Michael de Miranda</b> (pg. 103 - 115)	From High to Low Voltage: A genre approach for teaching to write about designing <b>Gerald van Dijk, Sacha Toppel and Maaik Hajer</b> (pg. 132 - 139)
14:50 - 15:15	Innovating a professional technology teaching programme based on student teachers' expectations and experience of work-integrated learning <b>Werner Englebrecht</b> (pg. 116 - 122)	Making it work: A case study of Canadian intermediate technology educators' pedagogical classroom practice <b>David Gill</b> (pg. 140 - 147)
15:15 - 15:40	Considerations for developing integrated-stem courses at the senior secondary school level in New Zealand <b>Bruce Granshaw and Cedric Hall</b> (pg. 123 - 131)	Supporting Discourse using Technology-Mediated Communication: The Community of Inquiry in Design and Technology Education <b>Adrian O'Connor, Niall Seery and Donal Canty</b> (pg. 148 - 155)
15:40 - 15:45	<b>Break and Refreshments</b>	
<b>Parallel Sessions</b> 15:45 - 17:00	<b>Session 7:</b> <b>X103 Engineering Building</b>	<b>Session 8:</b> <b>Y103 Engineering Building</b>
15:45 - 16:10	Innovating an Initial Professional Education of Technology Teachers (IPETT) programme <b>Rina Grobler</b> (pg. 156 - 166)	Constructs of Quality and the Power of Holism <b>Richard Kimbell</b> (pg. 181 - 186)
16:10 - 16:35	Developing Technology Student Teachers' Volition Through Curriculum-Related Excursions <b>Francois Van As</b> (pg. 167 - 174)	Exploring the Potential for Identifying Student Competencies in Design Education through Adaptive Comparative Judgment <b>Scott Bartholomew, Emily Yoshikawa and Pat Connolly</b> (pg. 187 - 194)
16:35 - 17:00	Making industrial internships effective for the professional development of aspiring science teachers <b>Mandy Stoop and Rutger van de Sande</b> (pg. 175 - 180)	Implications of the Learning Sciences for the Unique Intent and Remit of Technology Education <i>Joseph Phelan, Niall Seery and Donal Canty</i> (pg. 195 - 200)
17:00 - 17:15	<b>Travel via bus to conference hotel</b>	
18:15 - 19:30	<b>Social Activity:</b> Walking Tour of Athlone	
19:30	<b>Social Activity:</b> BBQ at Sean's Bar with Traditional Irish music session	

## Tuesday 19th June

**8:30 - 8:40** Travel via bus to AIT

**9:00 - 10:0**  
**X103**  
**Engineering**  
**Building**

**Plenary Session 1:**

**Theme 1 – Cultivating Imagination and Creativity**

A keynote address will be delivered by **Sean Ó Broin**, former Assistant Head of the State Examinations Commission. This will be followed by a plenary discussion.

**Discussion Panel – Sean O’Broin, Kay Stables, Joe Phelan**

**10:10 - 10:30**

**Break and Refreshments**

**Parallel Sessions**  
**10:30 - 11:45**

**Session 9:**  
**X103 Engineering Building**

**Session 10:**  
**Y103 Engineering Building**

**10:30 – 10:55**

Speculative Writing: Enabling Design Thinking  
**Belinda von Mengersen**  
(pg. 201 - 206)

Cultural and historical roots for design and technology education: why technology makes us human  
**Matt Mclain, Dawne Bell, David Wooff and David Morrison-Love**  
(pg. 223 - 230)

**10:55 – 11:20**

Developing Creativity and Imagination in Native Hawaiian Adolescents  
**Toni Marie Kauai, Kamalani Doria, Kainalu Gomera, Samuel M. Kamakau IV, and Quinn Waiki**  
(pg. 207 - 215)

Girls’ engagement in technology education: A systematic review of the literature  
**Ulrika N. Sultan, Cecilia Axell and Jonas Hallström**  
(pg. 231 - 238)

**11:20 – 11:45**

Connecting Authentic Innovation Activities to the Design Process  
**Joachim Svärd, Konrad Schönborn and Jonas Hallström**  
(pg. 216 - 222)

Teacher students’ critical thinking skills using the concept of disruptive technologies  
**Cecilia Axell and Lars Björklund**  
(pg. 239 - 245)

**Parallel Sessions**  
**11:45 - 13:00**

**Session 11:**  
**X103 Engineering Building**

**Session 12:**  
**Y103 Engineering Building**

**11:45 – 12:10**

Investigating T/E Design Based Learning: Student Ability to Select and Utilize STEM Content and Practices  
**Susheela Shanta and John G. Wells**  
(pg. 246 - 255)

Supporting Learning Design Language in Primary Education  
**Miroslava Silva Ordaz, Remke Klapwijk and Gerald Van Dijk**  
(pg. 270 - 277)

**12:10 – 12:35**

On Intelligence in Technology Education: Towards Redefining Technological Capability  
**Jeffrey Buckley, Niall Seery, Donal Cauty and Lena Gumaelius**  
(pg. 256 - 262)

Attention and Action during the Design and Technology lesson: by fine-tuning of task characteristics  
**Annemarie Looijenga, Remke Klapwijk and Marc de Vries**  
(pg. 278 - 287)

**12:35 – 13:00**

Investigating the Relationships between Spatial Ability, Interest, and Task Experience on Knowledge Retention in Engineering Education  
**Tomás Hyland, Jeffrey Buckley, Niall Seery, Jason R. Power and Seamus Gordon**  
(pg. 263 - 269)

Interdisciplinary teaching in Swedish primary schools: Teachers’ perspectives of subject-matter integration in technology and history  
**Catherine Couturier, Lars Geschwind and Eva Hartell**  
(pg. 288 - 294)



13:00 - 14:00

**Lunch**

**Parallel Sessions**  
14:00 - 15:15

**Session 13:**  
**X103 Engineering Building**

**Session 14:**  
**Y103 Engineering Building**

14:00 – 14:25

A preliminary model of problem categorisation to explore the cognitive abilities required for problem solving in engineering education  
**Clodagh Reid, Rónán Dunbar and Jeffrey Buckley**  
(pg. 295 - 301)

Teachers' Views on Training Spatial Skills and Creative Thinking by Using Model Construction. - A Case Study from South Korea and Sweden  
**Lena Gumaelius Mariana Black and Tom Callen**  
(pg. 319 - 326)

14:25 – 14:50

Pupils' Goal Orientations in a Pedagogical Innovation Process: A Competition to Design and Manufacture Quick Hydrocopters  
**Eila Lindfors, Vilma Heinola and Suvi Kolha**  
(pg. 302 - 308)

Spatial Ability and Approaches to Solving Word Problems in Mathematics  
**Gavin Duffy, Brian Bowe and Sheryl Sorby**  
(pg. 327 - 332)

14:50 – 15:15

Developing a learning environment for innovation learning in craft, design and technology education  
**Juha Jaatinen and Eila Lindfors**  
(pg. 309 - 318)

A National Spatial Skills Research & Development Project  
**Brian Bowe, Rachel Harding, Theresa Hedderman and Sheryl Sorby**  
(pg. 333 - 340)

15:15 - 15:20

**Break and Refreshments**

15:20 - 16:50

**Workshop Sessions**

<b>Workshop 1:</b> Z103 Sheryl Sorby Spatial Ability	<b>Workshop 2:</b> X206 Niall Murray AR/VR	<b>Workshop 3:</b> V109 Sean Lyons Additive Manufacturing	<b>Workshop 4:</b> X207 Enda Fallon ICT
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16:50 - 17:05

**Travel via bus to conference hotel**

18:00 - 19:30

**Social Activity:** Viking Boat to Glasson Hotel and Golf Club

19:30

**Social Activity:** Meal at Glasson Hotel

## Wednesday 20th June

**8:30 - 8:40**      **Travel via bus to AIT**

**9:00 - 10:10**  
**X103**  
**Engineering**  
**Building**

**Plenary Session 2:**

**Theme 1 – Learning through Design and Make**

**A keynote address will be delivered by Paddy Keays, former director of the Professional Development Service for Teachers (PDST). This will be followed by a plenary discussion.**

**Discussion Panel – Paddy Keays, Richard Kimbell, Nicolaas Blom**

**10:10 - 10:30**

**Break and Refreshments**

**Parallel Sessions**  
**10:30 - 11:45**

**Session 15:**  
**X103 Engineering Building**

**Session 16:**  
**Y103 Engineering Building**

**10:30 – 10:55**

Maker education in the English context  
**David Barlex and Torben Steeg**  
(pg. 341 - 346)

Reconceptualising PCK research in D&T education: Proposing a methodological framework  
**Andrew Doyle, Niall Seery, Lena Gumaelius, Donal Canty and Eva Hartell**  
(pg. 363 - 370)

**10:55 – 11:20**

Better making or making better: Exploring the attitudes of a school community to introducing a forge and blacksmithing into their school  
**Tony Lawler, Kim Ollif-Cooper, Kay Stables, Dominic Callaghan and Ralph Harris**  
(pg. 347 - 355)

Investigating the Potential for RGT and ACJ towards deeper insights of Teacher Assessment Practices  
**Eva Hartell and Helena Isaksson Persson, Scott Bartholomew, Greg Strimel**  
(pg. 371 - 377)

**11:20 – 11:45**

Learning to weld in technical vocational education: the first cycle of an action-oriented study  
**Nina Kilbrink and Stig-Börje Asplund**  
(pg. 356 - 362)

Addressing the issue of bias in the measurement of reliability in the method of Adaptive Comparative Judgment  
**Camila Rangel-Smith and Declan Lynch**  
(pg. 378 - 387)

**Parallel Sessions**  
**11:45 - 13:00**

**Session 17:**  
**X103 Engineering Building**

**Session 18:**  
**Y103 Engineering Building**

**11:45 - 12:10**

Pre-service teachers' subject knowledge in secondary design and technology: Findings from an empirical study  
**Mike Martin**  
(pg. 388 - 393)

Applying Project Based Learning to Teaching Robotics in Junior-high Schools  
**Yair Zadok**  
(pg. 411 - 416)

**12:10 - 12:35**

Establishing Progressions of Learning in Engineering for High School Students  
**Greg Strimel, Michael Grubbs, Tanner Huffman and Scott Bartholomew**  
(pg. 394 - 399)

Toward an Understanding of Dysgraphia as a Barrier to STEM Related Careers  
**Daniel Kelly and Deidre Kelly**  
(pg. 417 - 422)

**12:35 - 13:00**

Professional Development Program for Teaching Engineering-Focused Curricula in Technology Education  
**Kuang-Chao Yu, Szu-Chun Fan and Kuen-Yi Lin**  
(pg. 423 - 410)

Using a problem solving toolkit – in an international distance learning course  
**Osnat Dagan**  
(pg. 423 - 431)

**13:00 - 14:00**

**Lunch**

**14:00 - 15:00**

**X103**

**Engineering  
Building**

**Voices from Our Schools**

This session will give delegates an opportunity to get a flavour of the activities and outcomes from the Technology Education subjects in secondary schools in Ireland. A range of project work will be on display from the 8 technology based subjects (4 Junior level and 4 Senior level) on the Irish curriculum. An additional representation of extra-curricular technology related activities will also be presented. You will get opportunity to meet second level students and teachers from the following schools:

- **Scoil Mhuire, Kanturk, Co. Cork**
- **Portmarnock Community School, Co. Dublin**
- **Mercy Secondary School, Ballymahon, Co Longford**
- **Coláiste Naomh Cormac, Kilcormac, Co. Offaly**

**15:00 - 15:20**

**Conference Tour: Travel to Kilbeggan**

**15:20 - 16:20**

**Tour of Kilbeggan Distillery**

**16:20 - 16:45**

**Travel from Kilbeggan to conference hotel**

**19:30**

**Conference Dinner**

## Thursday 21st June

### Sessions will take place in the conference hotel

9:00 - 10:10  
Burke Suite

#### Plenary Session 3:

##### Theme 1 – Driving Social Change

A keynote address will be delivered by **Gerald Crotty**, teacher of Technology in Scoil Mhuire, Kanturk Co. Cork. This will be followed by a plenary discussion.

Panel – **Gerald Crotty, Stephanie Atkinson, Ulrika Sultan**

10:10 - 10:30

#### Break and Refreshments

Parallel Sessions  
10:30 - 12:10

#### Session 19: Grace Suite 1

#### Session 20: Grace Suite 2

10:30 – 10:55

Design Values, Preferences, Similarities, and Differences across Three Global Regions  
**Scott Bartholomew, Emily Yoshikawa, Eva Hartell and Greg Strimel**  
(pg. 432 - 440)

Project-based learning in technology education: implications of the digital era  
**Moshe Barak**  
(pg. 468 - 474)

10:55 – 11:20

Implementing Digital Technology in the New Zealand Curriculum  
**Wendy Fox-Turnbull**  
(pg. 441 - 452)

Multiple Design Representations to Foster Idea Development  
**Keelin Leahy**  
(pg. 475 - 489)

11:20 – 11:45

A model for food literacy education  
**Wendy Slatter and Bev France**  
(pg. 453 - 460)

Teaching young people to respond to a contextual challenge through designing and making – a discussion of possible approaches  
**David Barlex and Torben Steeg**  
(pg. 490 - 497)

11:45 – 12:10

Food Education in the School Curriculum: A Discussion of the Issues, Influences and Pressures on the Teaching of Food  
**Marion Rutland**  
(pg. 461 - 467)

Drawings to depict or drawings to explain: A whole-school analysis of children's drawings of bridges  
**Louise Milne**  
(pg. 498 - 505)

12:10 - 13:00

#### Lunch

Parallel Sessions 13:00 - 13:50	Session 21: Grace Suite 1	Session 22: Grace Suite 2
13:00 – 13:25	Effects of Convergent and Divergent Feedback on Creative Thinking During Children’s Design Processes <b>Alice Schut, Remke Klapwijk and Mathieu Gielen</b> (pg. 506 - 512)	Teaching Sustainability in Technology Education: Perception versus Practice <b>Beineán Conway, Keelin Leahy and Muireann McMahon</b> (pg. 521 - 534)
13:25 – 13:50	Perceptions and reality: Analyzing student experiences in ranking self and peer work through Adaptive Comparative Judgment <b>Scott Bartholomew, Emily Yoshikawa and Greg Strimel</b> (pg. 513 - 520)	Scientific and Technological Processes in K-12 classrooms in Quebec Schools: Common Features and Differences <b>Brahim El Fadil, Abdelkrim Hasni, Joël Lebeaume</b> (pg. 535 - 541)
13:50 – 14:15		Using Engineering Design Challenges to Promote Imagination and Innovation in Integrative STEM Education <b>Edward Reeve</b> (pg. 542 - 550)
14:15 - 14:30 Burke Suite	Closing of Conference- Dr Niall Seery	



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