The Importance of Spatial Ability within Technology Education

Jeffrey Buckley[1,2], Niall Seery[2], Donal Canty[3], and Lena Gumaelius[1,4]

[1]*KTH Royal Institute of Technology, Stockholm, Sweden.*
[2]*Athlone Institute of Technology, Westmeath, Ireland.*
[3]*University of Limerick, Limerick, Ireland.*
[4]*Mälardalens Högskola, Västerås, Sweden.*

Abstract Understanding the factors that impact learners with respect to their academic achievement is critical for enhancing educational provision, and the nature of these factors can vary widely. They could be, for example, cognitive, conative, physiological, or physical. With increased understanding of such factors teachers can better meet learner needs. Investigations into individual differences are not uncommon within technology education, for example much work has been conducted in the area of attitudes towards technology. However, research into individual cognitive differences is an emerging space.

In light of the overwhelming evidence illustrating that spatial ability, commonly described as the ability to generate and manipulate abstract visual images, is positively associated with STEM educational performance and retention, understanding the role of spatial ability in technology education is important. Acknowledging the potential implications of such insight but recognizing the lack of contextual evidence, this chapter describes the results of a series of studies conducted with the aim of supporting the development of theory and suggesting recommendations for practice with respect to spatial ability within technology education. A literature review of the extant literature on spatial ability was conducted, and four quantitative studies examined the theorised positionality of spatial ability within technology education, and its relationship with authentic problem solving and other cognitive factors.

Key words: Spatial ability, Technology education, STEM education, Intelligence, Educational performance.

The questions asked and why they are important

There is a wide range of variables that teachers need to contend with when teaching young people. Detterman (2016) categorises these into student variables and school variables. Student variables describe characteristics unique to each individual student, such as intelligence and motivation, while school variables refer to aspects of schooling which affect groups of students within a school, such as teacher quality and class size. Understanding the impact of different variables on desirable student outcomes offers the potential to enact meaningful educational change as interventions such as policy development or pedagogical refinement could target impactful factors. Relating to this, Detterman (2016) identified student variables as being able to account for approximately 90% of the variance in student academic achievement and school variables as accounting for approximately 10% of this variance. More specifically, he found that individual differences in intelligence alone accounted for between 50% and 80% of the total variance, and this finding has seen large scale corroborating evidence from O'Connell (2018) and Smith-Woolley et al. (2018).

In parallel to the evidence which indicates a relationship between intelligence and academic achievement, specifically in science, technology, engineering and mathematics (STEM) fields substantial evidence links spatial ability, a factor of intelligence, with performance and retention. Wai, Lubinski and Benbow (2009) present longitudinal evidence for this, and there is additional evidence linking spatial ability to specific subject areas such as design and technology (Buckley, Seery, & Canty, 2019; Khoza, 2017; Lin, 2016), mathematics (Cheng & Mix, 2014; Sorby et al., 2013), physics (Kozhevnikov et al., 2007) and computer programming (Jones & Burnett, 2008). Further to this and important from an educational perspective is that unlike intelligence (Owen et al., 2010; Simons et al., 2016), spatial ability can be developed through targeted educational interventions (Uttal et al., 2013) and this can transfer to improved performance and retention (Sorby et al., 2018).

Based on this evidence, the relationship between spatial ability and academic achievement became the focus of this work. While there are many theories as to why spatial ability is associated with STEM outcomes, there is yet to be a unifying causal explanation which limits the capacity for the translation of evidence into practice. Existing theories include quite direct relationships such that STEM activities often involve the need to mentally rotate objects (such as when imagining molecular structures in chemistry), interpret cross sections (such as in interpreting x-rays in medicine), and imagine exploded views (such as in understanding the components of an electrical plug-in technology), and as such it is theorised that correlations exist as a result of educational activities mirroring spatial processes (e.g., Atit et al., 2020; Gaughran, 2002; Uttal & Cohen, 2012). Other theories relate to roles of additional cognitive mechanisms such as spatial ability being predictive of STEM education performance through an interaction with relevant discipline knowledge (Hambrick et al., 2012) or by affecting information processing in students working memories (Hyland et al., 2018, 2019). In an effort to contribute towards a causal theory, the following research questions (RQ) were developed which placed specific emphasis on spatial ability being viewed as a factor of intelligence:

RQ1. How does the context of technology education impact research investigating the relationship between intelligence, in particular spatial ability, and STEM education?

RQ2. How do levels of spatial ability affect problem solving performance in technology education?

RQ3. What is the nature of the current evidence which illustrates the correlation between spatial ability and STEM education?

RQ4. How is spatial ability perceived to align with technology teacher education students' perceptions of intelligence in STEM?

RQ5. How is spatial ability psychometrically related to other perceived factors of intelligence in STEM education?

How we tried to answer the questions

Each research question was attended to through an individual study with each having its own unique method and with much of the data collection being completed in Ireland. RQ1 was conceived with the view that technology subjects have unique characteristics to other STEM areas due to their applied nature and the presence of technological knowledge (Buckley, Seery, Power, et al., 2019). To explore this from a performance perspective, longitudinal data of Leaving Certificate performance in Ireland was collected from five schools over a five-year period (n = 1761). The Leaving Certificate is a state examination which is taken at the end of post-primary education in Ireland, it serves as the primary matriculation system to third level education, and exams are designed and administered by an independent body, the State Examinations Commission. This data was explored to see the relationship between overall performance in the Learning Certificate relative to studying the technology subjects or the sciences which are optional in the Irish system. Further, it was examined to see the impact of studying a single versus multiple technology subjects. Differences in performance as a result of subject choice served as an indication for variance in subject context.

RQ2 sought to investigate if having a high level of spatial ability was related to performance in technology education. Viewing graphics as a common language within the technologies (Baynes, 2017; Danos, 2017) and to eliminate the potential influence of discipline knowledge, undergraduate students (n = 215) in an initial technology teacher education programme completed a series of geometric problems and psychometric tests of spatial ability (Buckley, Seery, & Canty, 2019). The solutions for the problems, both in terms of performance and approach taken, were examined relative to the students' levels of spatial ability.

To address RQ3, which sought to determine the current state of knowledge with respect to the relationship between spatial ability and STEM, a narrative literature review was conducted (Buckley, Seery, & Canty, 2018a). The aim of this was to present a working definition for spatial ability in terms of individual cognitive factors, i.e., to describe comprehensively the various components of spatial ability such as the ability to mentally rotate geometries and to accurately imagine geometries from alternative perspectives. In addition, understanding the various components of spatial ability would permit a more accurate review of how it relates to STEM education.

RQ4 and RQ5 were very much related in that RQ4 aimed to determine the implicit understanding of intelligence in terms of different intellectual factors held by undergraduate technology teacher education students and RQ5 then explored explicit relationships between these factors. The participants were selected because they had a unique perspective of being students of technology education, engaging with contemporary perspectives on technology education, and regularly interacting with academics in the field through their studies. A survey method was used to address RQ4 whereby volunteering students (n = 205) were first asked to list the components they believed contributed to intelligence in STEM and after this, once the responses were compiled, volunteering students from the same population (n = 213) were asked to rate how important each component was to their own conception of intelligence in STEM. The analysis then resulted in a model which depicted the factors of intelligence thought to be most important for describing intelligence in STEM from the perspective of Irish undergraduate technology education students and their relative weightings of perceived importance (Buckley, O'Connor, et al., 2019). These results and the findings in relation to RQ3 were then used to design a method to address RQ5 (Buckley, Seery, Canty, et al., 2018). Two studies were employed for this which involved psychometric indicators for various factors of intelligence based on empirical frameworks (Schneider & McGrew, 2018) and the results of the previously described work being administered to a similar sample of undergraduate technology teacher education students. In the first study, a sample of volunteering students (n = 85) were administered 17 psychometric tests so that various factors of intelligence could be explored to determine their relationship with fluid intelligence, the closest factor of intelligence to general intelligence (Ebisch et al., 2012). In the second study, the factors of intelligence which had a significant relationship with fluid intelligence in the first study were explored again with a new sample of volunteering students (n = 87) and additional psychometric tests in a conceptual replication. This resulted in a model which described, in the context of intelligence, why spatial ability could be contributing to academic performance in STEM education, and more specifically in technology education.

What was found out

Much research relating spatial ability to STEM does not take technology education into account and instead focusses on science, mathematics, and engineering. While there are many parallels between STEM areas, technology education does have qualitatively unique characteristics such as the treatment of design and prevalence of provisional knowledge application. There were several results which related specifically to this in the first study which explored student performance in the Leaving Certificate in Ireland. The total points in the Leaving Certificate for each student were calculated and they were then divided into quartiles, i.e., quartile 1 (Q1) described the poorest performing 25% of students overall and quartile 4 (Q4) described the highest performing 25% of students overall. The relationships between enrolment within the four technology subjects (Design and Communication Graphics [DCG], Construction Studies, Engineering, and Technology) and being in different quartiles were all statistically significant, and interestingly, students who studied the technologies and more applied subjects such as Art and Home Economics were less likely to be in the top 25% of students based on overall performance than those who chose to study less applied subjects such as Mathematics, modern languages and the natural sciences (Figure 1). Further, the more technology subjects a student studied the more likely they were to find themselves in the lowest quartile overall. Finally, it was found that student performance in their technology subjects, whether they studied one, two or three of them, was generally greater than their average performance across all their other subjects. It should be noted that all students would typically study Mathematics, English and Irish as most schools offer these as compulsory subjects. Based on the results of this study, it was inferred that there was a general systematic advantage to studying subjects which were more closely aligned with these compulsory subjects, i.e., subjects with a greater emphasis on knowledge acquisition and a systematic disadvantage to enrolling in optional subjects which placed a greater emphasis on knowledge application. This of course does not reflect student variables which could see the reverse true on an individual level. The distinction, albeit along a continuum, from more to less application within a subject area provides evidence that the qualitative differences in context between technology and other STEM areas position technology as a unique subject in which to explore individual differences in intelligence.

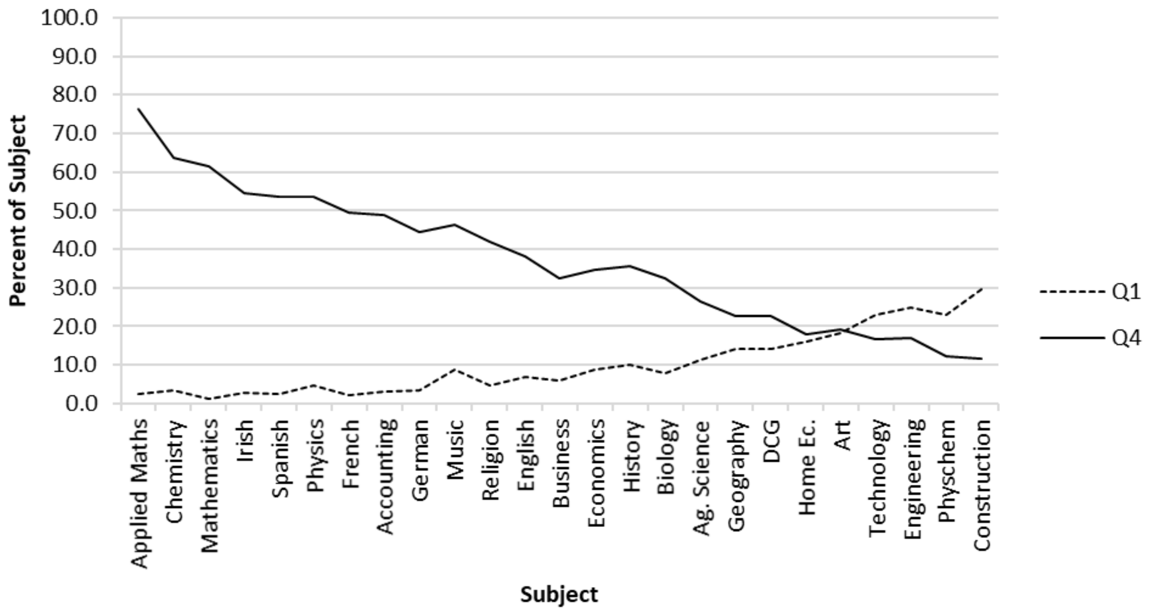

Figure 1. Statistically significant distributions between Q1 and Q4 for Higher level subjects. Subjects are ordered (left to right) based on the variance between the percentage of students in Q1 and Q4 from Buckley, Seery, Power, et al. (2018).

The second study looked more specifically at how spatial ability, as measured across paper and pencil psychometric tests, related to performance in technology education problems. In Ireland at least, graphics can be viewed as a common element across the technology subjects, so it was selected for the case study. Also, task related knowledge can influence performance (Hambrick et al., 2012) so it was considered useful to explore performance in a graphical problem where discipline knowledge, other than what was necessary to interpret the geometries, was not necessary. What was of particularly interest here was whether having a higher level of spatial ability correlated with increased performance in the problems. Taking one problem from within a variety of problems for an in-depth analysis (Figure 2) students were divided into quartiles, however this time it was based on their level of spatial ability. It was observed that students with higher levels of spatial ability performed better on the graphical task. This provided the first insight that spatial ability could be related to performance in at least certain aspects of technology education. Further to this, of particular interest was how students with varying levels of spatial ability engaged with the problem. To aid themselves in solving the problem, students used strategies such as creating separate isometric sketches of the dice, indexing or labelling the vertices of the cube, editing the provided development in ways to make mapping the dice detail easier, adding hidden detail to the orthographic views, converting the dice detail to numeric digits, and adding additional orthographic detail. The most used strategies were to create an additional isometric sketch and index the cube vertices, and it was found that students who had lower levels of spatial ability used these strategies more frequently than those with higher levels of spatial ability. It is possible that these strategies were applied to augment their lower spatial skills, and therefore any progression of investigations on the association between spatial ability and technology education performance needs to take forms of potential external thinking into account.

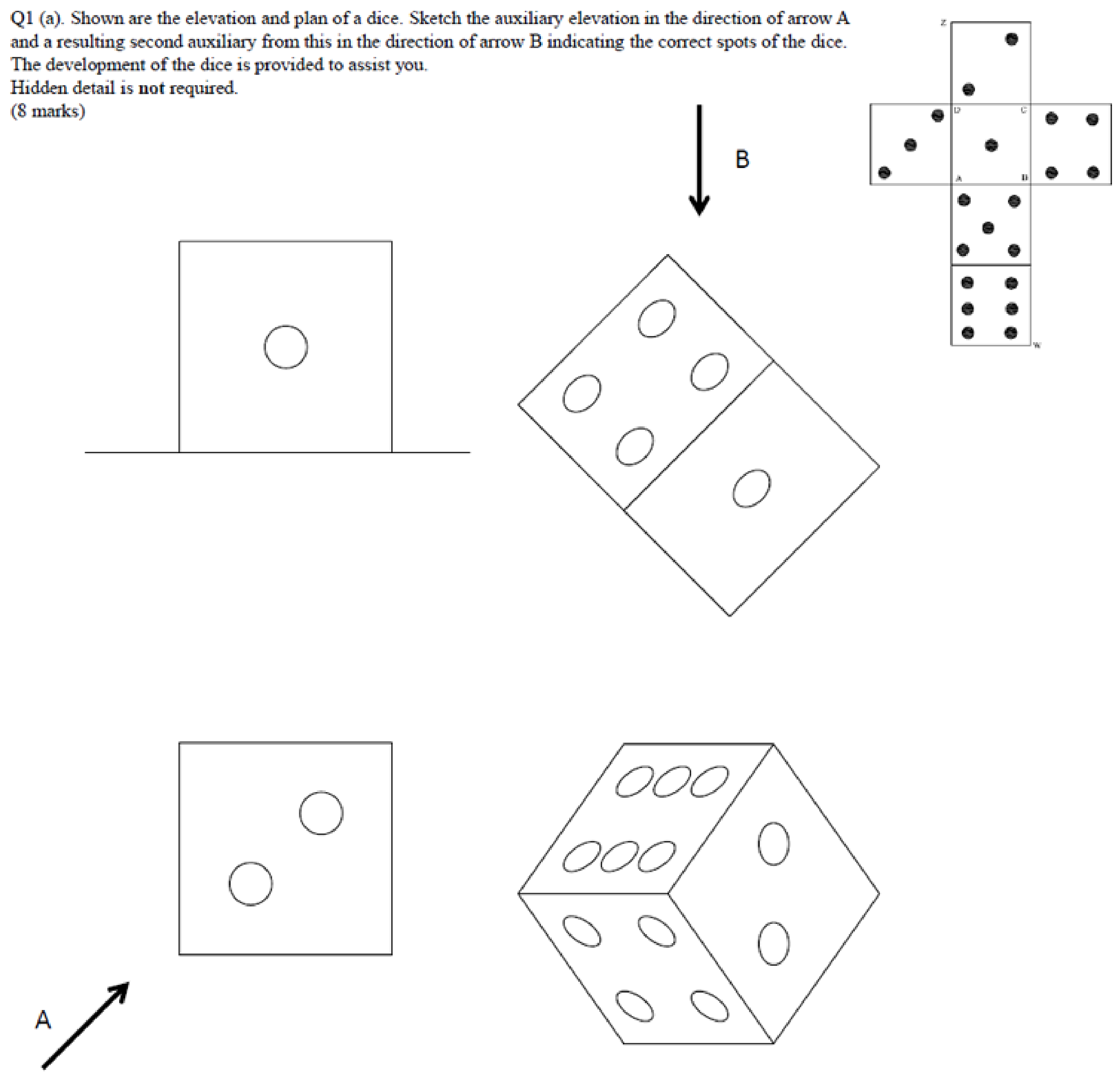

Figure 2. Solution to graphical problem posed to participants. The solution required producing the first and second auxiliary views in the directions of arrows A and B respectively. Performance was evaluated based on correct orientation of the cube and positioning of the dice detail, not on quality of the presentation.

The third study involved completing a narrative literature review of spatial ability research. Since its inception by Galton, spatial ability has been recognised as comprising of multiple components or factors (Galton, 1879a, 1879b, 1880, 1881). Over time, knowledge of these factors has been refined (Carroll, 1993; Lohman, 1979; Schneider & McGrew, 2012) and in current frameworks spatial ability is described as having 11 factors (Schneider & McGrew, 2012). Examples of these include the *visualisation* factor which is described as "the ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g., rotated, changes in size, partially obscured)", the *imagery* factor which is described as "the ability to mentally produce very vivid images", and the *speeded rotations* factor which is described as "the ability to solve problems quickly by using mental rotation of simple images" (Schneider & McGrew, 2012, pp. 129–130). The implication for this is that by saying spatial ability is related to STEM outcomes, there is a degree of uncertainty as to what factor of spatial ability is being described. In practice, the most accurate way to describe spatial ability is relative to the instruments used to measure it (Meehl, 2006) but there was a need for a more comprehensive working definition and framework to guide the progression of this work.

The narrative review revealed many more spatial factors than are described in current frameworks (Buckley, Seery, & Canty, 2018a). This was largely a result of technological advances leading to new possibilities for computerised testing of dynamic spatial factors, i.e., moving stimuli not possible in paper and pencil tests. It also revealed that the visualisation factor, which is the strongest indicator of a general spatial ability (Carroll, 1993) and describes the ability to mentally manipulate complex geometries, is the factor with most evidence underpinning a relationship with STEM outcomes. This suggests that other factors may also be related but there is a lack of evidence for this and makes it clearer what is being described by the term spatial ability.

The fourth study then progressed to asking what, from the perspective of Irish technology teacher education students, broadly describes intelligence in STEM. It was of interest to determine whether spatial ability was part of this implicit theory. The result of the survey method was a model indicating that intelligence in STEM was viewed as comprising of three factors, a social competence which had the weakest loading on the student's overall conception of intelligence, a general competence, and a technological competence which had the highest loading on their overall conception of intelligence (Figure 3).

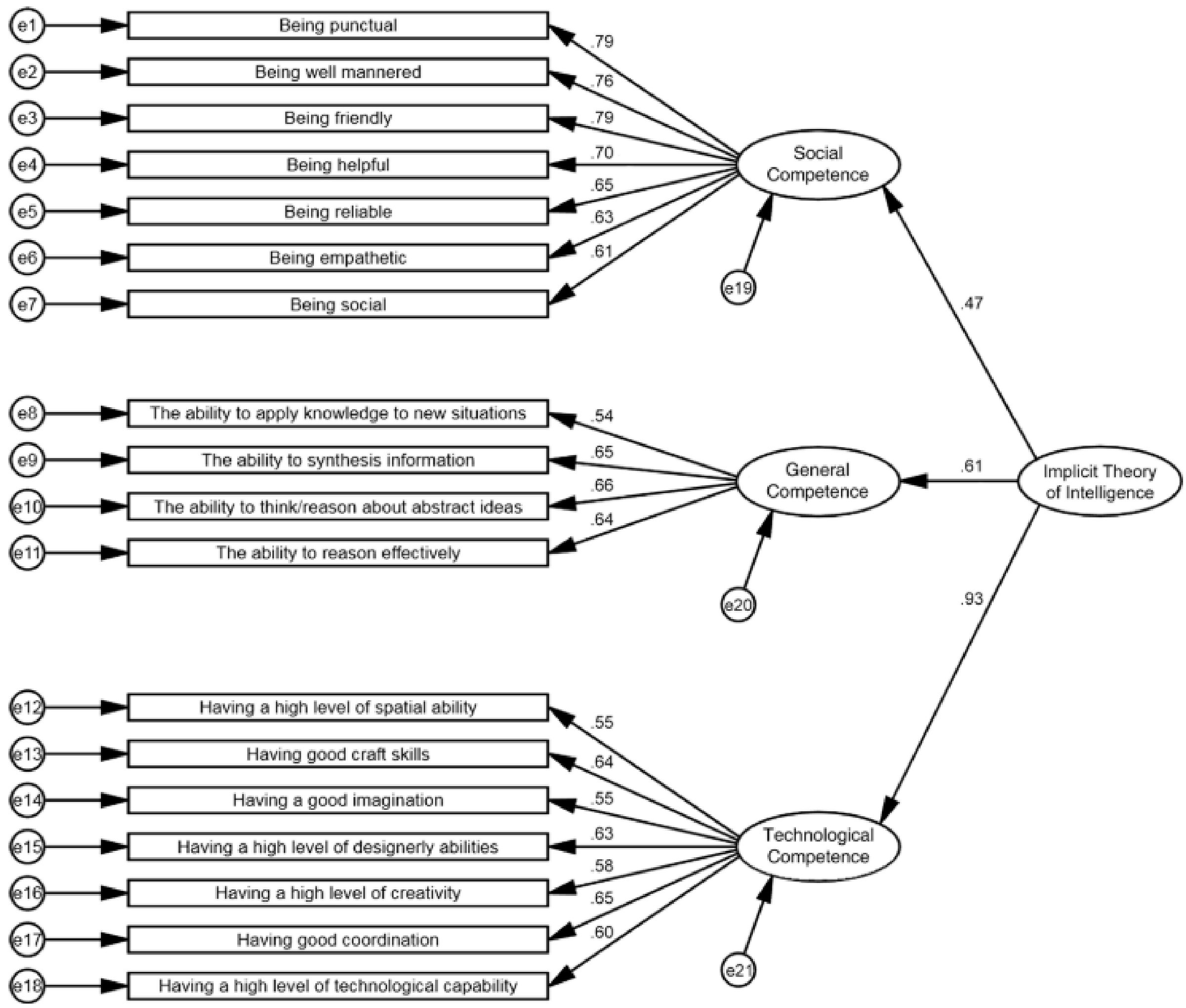

Figure 3. Implicit theory of STEM intelligence from Irish undergraduate technology teacher education students (Buckley, O'Connor, et al., 2019).

The technological competence factor was of particular interest as it further strengthens the inference made from the first study that technology education provides a unique context for exploring spatial ability in STEM education. Its interpretation is akin to the concept of technacy, defined as "the ability to understand, communicate and exploit the characteristics of technology to discern how human technological practice is necessarily a holistic engagement with the world that involves people, tools and the consumed environment, driven by purpose and contextual considerations" (Seemann, 2009, pp. 117–118). Within this factor, spatial ability was deemed to be an important descriptor of STEM intelligence giving validity for examining the relationship between spatial ability and intelligence in this context explicitly. What was arguably most interesting was the lack of indication that a degree of discipline knowledge was viewed as contributing to an intelligent person in this context. This of course does not mean that the students did not view discipline knowledge as important, just that it was not a perceived descriptor of an intelligent person in STEM. A prominent theory of intelligence is the theory of fluid and crystallised intelligence (Horn & Cattell, 1966). In this theory, the construct of a single general intelligence is conceived as comprising of two dimensions, fluid intelligence which relates to novel problem solving and crystallised intelligence which reflects acquired knowledge. As no evidence was found that a factor similar to crystallised intelligence described intelligence but the general competence factor aligned with fluid intelligence, only fluid intelligence was considered with respect to general intelligence in the fifth study which sought to examine relationships between a variety of specific factors and intelligence explicitly.

Where the fourth study explored undergraduate technology teacher education students' implicit theories of intelligence, the fifth study investigated intelligence in this population explicitly (Buckley, Seery, Canty, et al., 2018). A sample of these students were administered psychometric tests for 16 specific factors of intelligence such as the visualisation factor, and for the broad factor of fluid intelligence. Of the 16 specific factors, 9 were spatial factors based on the narrative review in the third study, with the others associated with factors of long-term memory, short-term memory, processing speed, and general reasoning. A regression analysis indicated that visualisation, inductive reasoning and memory span were predictive of fluid intelligence and this was then found to replicate in a second study. This result presents a causal theory for how spatial ability could relate to STEM performance. Fluid intelligence has general educational significance (Lohman, 1996) as it has been identified as a causal factor in learning as it supports the acquisition of knowledge (Kvist & Gustafsson, 2008; Primi et al., 2010). Memory span affords the capacity to retrieve and hold chunks of information in the working memory while engaging with a problem or task. Visualisation enables this information to be generated, represented, and manipulated. Finally, inductive reasoning allows for students to draw inferences based on the available information. It is possible that if technology education were not the context for this research and instead an area of STEM with a greater emphasis on knowledge acquisition was used that fluid intelligence would not have been presented as a mechanism for the association between spatial ability and STEM performance. However, the result of this is now a testable theory for exploring the impact of spatial ability in technology, and more broadly in STEM education.

How this might be used to improve teaching and learning

Situating the research within technology education

There are several ways in which the results of this work could be used to improve teaching and learning in technology education and more broadly in STEM fields. First though, it is important to remember that to date there has been a lack of research in technology education relating to intelligence and spatial ability so there is need for more research in this space to better inform associated educational change (cf. Buckley, 2020 for an extended discussion). Spatial ability was a consistent focus of this research, however the context of technology education is an important dimension. Research clearly illustrates a link between spatial ability and discipline knowledge

(Hambrick et al., 2012; Uttal & Cohen, 2012), and technological knowledge and its treatment have specific qualities which highlight the importance of spatial ability for technology students. For a comprehensive description of technological knowledge from a philosophical perspective readers are encouraged to read de Vries' (2016) *Teaching about Technology*. However, one characteristic of the treatment of technological knowledge which is critical to this discussion is noted by Kimbell (2011) when he says:

> What we do is formulate a view of knowing that empowers learners to take action with *provisional* knowledge – and that encourages them to refine and deepen that knowledge in response to the demands of the task. So we have deliberately transposed the issue of 'knowing' stuff into the business of 'finding-out-about' stuff (p. 7).

Students in technology education, particularly due to the inclusion of design and regular engagement with novel problems (cf. Buckley et al., 2020 for an extended discussion) must frequently acquire knowledge which may only have relevance to a specific problem at hand and for a short period of time. This may be the reason why, in the survey methodology used in response to the fourth research question, a discipline knowledge factor was not viewed by undergraduate technology teacher education students as a defining characteristic of intelligence in STEM. This relationship with knowledge is being highlighted here with the intention that readers maintain this idea as they continue through the discussion. As an aside, in Buckley, Seery, Power, et al. (2019) there is an extended discussion about technological knowledge from a policy perspective where the inclusion of technology curricula as a core part of all post-primary students' educational experience is advocated for. Such policy decisions are a critical aspect of teaching and learning. This space, however, will be used to consider the implications of the work in this thesis specifically within a technology classroom in the context of pedagogy.

Policy recommendation

With respect to spatial ability, at least in Ireland within the post-primary subjects of Graphics (lower secondary level) and Design and Communication Graphics (upper secondary level), subject level aims include the development of visualisation. From the literature review conducted, visualisation can be understood as one of many factors of spatial ability, however it is the factor which has the most empirical evidence linking it with desirable educational outcomes. For the broader remit of technology curricula internationally, alongside discipline goals such as the development of technological capability and/or technological literacy and general goals such as the development of numeracy and literacy, it would be of value for policy to reflect the aspiration to positively affect spatial ability. Reasons for this include the association between higher levels of spatial ability and increased STEM performance and retention generally (Sorby et al., 2018; Wai et al., 2009), the relationship between spatial ability and fluid intelligence, as shown in the fifth study within this body of work, which is associated with learning in general (Kvist & Gustafsson, 2008; Primi et al., 2010), and as fluid intelligence is the closest, i.e., strongest correlating, factor of intelligence to general intelligence (Ebisch et al., 2012), the development of spatial ability may lead to some positive outcomes that are associated with higher levels of general intelligence. These include benefits to mental health, conscientiousness, happiness, risk perception and living longer (Ritchie, 2015). The links between spatial ability and knowledge acquisition should be seen as paramount here when reflecting on the need for technology students to often quickly find out about stuff in the context of a problem. Higher levels of spatial ability could support technology students to a great extent in negotiating the provisional knowledge described by Kimbell (2011), and also by regularly engaging with novel problems, technology students will often find themselves as novices with respect to the problem they are trying to solve. Higher levels of spatial ability are of greater benefit to students who are more novice relative to a specific educational task than to students who are more expert. Also, while the link between spatial ability and outcomes associated with general intelligence is speculative (but would be an interesting research avenue), it is inherently good to develop students' cognitive faculties as doing so facilities more complex thought. The question then becomes how this could be achieved in practice.

Approaches to developing spatial ability in the classroom

One of the aspects that makes spatial ability research so translatable to educational practice is that the related evidence indicates that it can be developed through targeted interventions (Uttal et al., 2013). At post-primary level, the intervention developed by Sorby has been shown to be successful by leading to increased STEM educational performance and retention on numerous occasions over the last two decades (Sorby et al., 2018). This presents an opportunity for educators to implement this intervention directly. In practice, this intervention is designed to be delivered over ten two-hour sessions, one session per week over ten weeks, where students engage with activities specifically designed to develop spatial ability. That said, the use of such an intervention is not always possible. Two inhibitors from the perspective of schools and teachers could be cost implications and time constraints. Recognising these, a second approach to developing spatial ability in classrooms is through what has been termed 'spatialising the curriculum'. The idea behind this is, rather than adding to an existing curriculum, to consider how the development of spatial ability could be integrated into pedagogical activities while students are engaging with curriculum defined discipline knowledge/learning outcomes. Newcombe (2017) describes a number of such activities which teachers could adopt and engage their students in including the use of symbolic systems such as maps, diagrams, graphs and in descriptive language, the use of analogy, and incorporating an action-to-abstraction process through students' movement, gesturing and sketching. Undoubtedly, all technology teachers will see where these types of activities can be incorporated into their practice, and many do so already. For example, sketching is a common activity in technology classrooms, students regularly iterate between 2- and 3-dimensional representations of objects, and the prevalence of modelling provides substantial opportunity for taking concrete objects and thinking about them as abstractions as elements are considered in alternative contexts. That said, it is worth thinking specifically about the technology classroom in the context of a hypothetical case study to reflect on meaningful use of such pedagogies and an important caveat.

By way of example, the use of computer aided design (CAD) is quite common in technology education. CAD expertise has been associated with spatial ability (Chester, 2007), CAD modelling behaviours have been explicitly explored in technology education (Buckley, Seery, & Canty, 2018b; Buckley & Seery, 2018), and CAD use has been investigated with respect to developing spatial ability (Yue & Chen, 2001). Considering how CAD is used is critical, and here CAD is serving as an analogy for any modelling activity which could support students visualising an idea such as sketching or making a physical model. The use of CAD has the capacity to both supplement a student in visualising a thought or idea and prevent the need for a student to mentally generate an image as the technology can do this for them. Therefore, it could be either aiding the development of spatial ability or inhibiting it. From a pedagogical perspective, and the results of Buckley, Seery, & Canty (2019) on geometric problem-solving behaviours support this, technology teachers should think about activities which can spatialise the curriculum both as scaffolds for developing spatial ability but also their potential to mitigate the need for this type of cognitive activity. Achieving this balance is not easy, especially within curricula that also require students to develop modelling expertise. What could work, and the idea of 'could' in this instance will be discussed more in the conclusion of this chapter with respect to potential for action research, is the development of pedagogical approaches wherein students transition from modelling activities where their idea is less realised to more realised. The model provided by Johnston-Wilder and Mason (2005) could be greatly beneficial here (Figure 4). For example, students could begin by discussing their ideas with peers (getting a sense of the idea), move onto sketching their ideas and then creating physical models (manipulating their ideas), and finally creating an accurate CAD model (articulating their ideas). This process would see students having to visualise their thinking prior to working with CAD where the function of using CAD in this instance could be to both develop modelling proficiency and to present an accurate representation of their design.

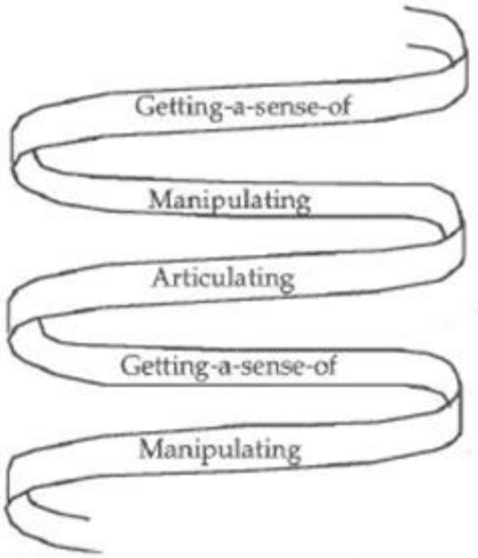

Figure 4. Model for effecting learning (Johnston-Wilder & Mason, 2005).

Conclusion

There are two important applied research questions which are of immediate interest to progressing spatial ability research in technology education. The first of these is best described using examples of recently published research. As previously noted, at least in Ireland, post-primary graphics education has a specific agenda to develop students' visualisation, an agenda which we would recommend be extended to technology subjects more generally. In a study by Prieto and Velasco (2010), the authors concluded that studying technical drawing resulted in the development of visualisation. However, a recent study by Contreras et al. (2018) found that visualisation improved both with and without studying technical drawing. By not including a control group to compare with, it appears that Prieto and Velasco (2010) observed natural development of visualisation in students from educational engagement rather than a specific effect of studying technical drawing. However, the method used by Contreras et al. (2018), which did involve a control group (who were enrolled in a mathematics course), involved a single sample of architecture students (studying technical drawing) being compared to mathematics students. It is therefore possible that some of the previously described school variables (such as class size, teacher quality etc.) impacted the results. A recommendation for future research would be to conduct a study whereby students studying graphics (or technology) from multiple schools (to reduce potential school variable effects) are compared with a control group consisting of students, again from multiple schools, not studying graphics/technology to see if there was an effect of graphics/technology education on the development of visualisation.

The second important research question relates to research which could be conducted within individual classrooms. As discussed, there is a need to understand how modelling relates to spatial ability development. There are two facets to this from a technology classroom standpoint. First, it would be of interest for teachers to investigate if certain modelling tools and techniques, i.e., CAD, sketching, having conversations with peers, making physical models, etc., which are accessible to teachers promote the development of spatial ability or inhibit its development. The pedagogical ordering of events is relevant for this with an example of a meaningful research question being whether requiring students to sketch their ideas before beginning CAD modelling improves spatial ability more than using CAD alone. The second aspect to this would be an extension, whereby modelling proficiency is considered. Taking CAD as an example for continuity (but again using it as an analogy for all modelling methods), it would be interesting to see if there is a difference in the use of CAD for the development of spatial ability between students with a high level of CAD proficiency compared to those with a low level of proficiency. One hypothesis could be that higher CAD proficiency supports spatial development as students are not negatively impacted by inability to use the technology. An alternative hypothesis could be that by having less CAD proficiency, more attention is required for the activity as a whole for students to accurately create a model and so therefore must better understand their model. Similarly, CAD modelling may have different effects on students with higher or lower levels of spatial ability. This line of research has the added value of comparing specific activities which can be more controlled than comparisons of whole subject effects, allowing for greater capacity to identity causal variables which can then be translated into policy and practice recommendations.

To conclude, the central theme which can be used to develop related action research projects for contributing to the current body of knowledge pertaining to the role of spatial ability in technology education is to determine what works, when and for whom.

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Author biographies

Dr Jeffrey Buckley is an Assistant Lecturer at Athlone Institute of Technology, Ireland and a researcher in engineering education at KTH, Royal Institute of Technology, Sweden. He is a member of the Technology Education Research Group and Engineering Education in Society research group. Jeffrey received his PhD from KTH in 2018 in the area of spatial ability and learning in technology education. His current research interests include the relationship between spatial ability and learning, diversity and inclusivity in engineering education, and methods and practices in technology and engineering education research.

Dr Niall Seery is currently a Vice President at Athlone Institute of Technology. Niall has a background in technology teacher education, where he spent 15 years as an academic with a specialist interest in pedagogical practice. In 2010, Niall founded and continues to direct the Technology Education Research Group, where he is still active in research supervision and mentorship. Niall also served as a visiting associate professor of technology education at KTH, Royal Institute of Technology, Stockholm. He remains committed to advocating for Technology and Engineering education research and supporting the development of associated policy and practice.

Dr Donal Canty is a qualified post-primary teacher with 8 years' classroom experience. Donal's research interests are in the areas of pedagogy and assessment with particular interest in utilising comparative judgment to enhance student learning and capability. Donal is one of the founding members of the Technology Education Research Group (TERG) and has led both national and international research projects. Donal has extensive experience of programme design for both secondary and higher education and is currently a lecturer in the School of Education at the University of Limerick.

Dr Lena Gumaelius is the Pro Vice-Chancellor at Mälardalens Högskola (MDH) where her main responsibility is education. Besides her duties at MDH, she works as an associate professor in engineering education at KTH, Royal Institute of Technology, Sweden, where she is leading the Engineering Education in Society research group. Her main research interest is in engineering and technology education, where she focuses on inclusiveness and attractiveness as well as education for sustainable development.