The predictive capacity of spatial ability for knowledge retention in third level technology and engineering education




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Abstract

It is well established that spatial ability correlates with STEM performance. This has been shown through substantial longitudinal evidence e.g. (Wai, Lubinski, & Benbow, 2009). Specifically, it has been demonstrated as an important factor in engineering and technology education consistently for the last two decades (Buckley, 2018; Sorby, 1999, 2009b). However, a causal explanation does not yet exist (Ramey & Uttal, 2017). Working with the hypothesis that spatial ability affects cognitive load while learning, this paper specifically investigates the impact it has on retention, a component of the information processing theory of learning (Simon, 1978), within an authentic classroom environment. This paper describes a conceptual replication of Hyland et al. (2018), investigating the effect of spatial ability on the ability to retain information associated with novel engineering concepts.

A cohort of students from within a common engineering module in an Institute of Technology in Ireland voluntarily participated in this study. Initially, three validated psychometric tests of spatial ability were administered to the cohort. After three weeks this was followed by an experimentally designed lecture on novel foundational engineering/technology content after which an associated retention test was administered. Perceived task experience and interest were also measured through 9-point Likert-type items at this time.

The result from Hyland et al. (2018) that spatial ability predicts knowledge retention associated with fundamental engineering concepts over and above interest was replicated. This is significant in terms of informing both pedagogy in technology and engineering fields, and for research associated with the foundational development of spatial ability.

Key Words: Engineering education, Spatial ability, Learning, Retention.

Introduction

Spatial ability, defined as “the ability to generate, retain, and manipulate abstract visual images” (Lohman, 1996, p. 126) has been found to correlate significantly with performance in Science, Technology, Engineering and Mathematics (STEM) disciplines (Wai et al., 2009). In terms of technology education, it has been found to correlate with performance on geometric problem solving tasks (Buckley, Seery, & Canty, 2018) and with performance in design (Lin, 2016). Similar findings are more prevalent in engineering education (Alias, Black, & Gray, 2002; Carbonell Carrera, Saorín Pérez, de la Torre Cantero, & Marrero González, 2011; Sorby, 2009a) and the importance of this correlation in terms of education is apparent through the variety of attempts made to design targeted spatial training interventions (Onyancha, Derov, & Kinsey, 2009; Sorby, Casey, Veurink, & Dulaney, 2013; Stieff & Uttal, 2015). Critically, spatial ability has been found to be malleable and susceptible to change through such interventions (Stieff & Uttal, 2015; Uttal et al., 2013). However, despite the work highlighting that spatial ability is educationally important and malleable, there is uncertainty as to why this cognitive ability has such profound implications (Ramey & Uttal, 2017).

It is posited that because spatial ability has been found to consistently correlate with STEM educational performance, that at some level it is having an impact on learning. 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". These definitions are associated with the information processing theory of learning which defines learning as "an active mental process involving the storage and retrieval of knowledge stored in memory" (Terrell, 2006, p. 254) and is based on the human cognitive architecture. In brief, the process of learning or acquiring knowledge involves a sensory input which is perceived in the sensory memory, assuming attention is given to this information it is then processed in the working memory and then encoded into the long-term memory. Once encoded, it can be retrieved from the long-term memory into the working memory again and is then visible through outputs such as educational test answers, behaviours etc. Sweller, Ayres and Kalyuga (2011) and Terrell (2006) provide a more accurate and complete description of this process. Assuming spatial ability has an effect on learning, based on this theory that suggests it has an effect on at least one of the cognitive processes associated with processing information. Therefore, it could affect how information is perceived, stored in short-term memory, processed in the working memory to be encoded into the long-term memory, and/or retrieved from the long-term memory. This study aims to investigate the potential impact that spatial ability has on the retention of information in the short-term memory, and is a conceptual replication of Hyland, Buckley, Seery, Power and Gordon (2018)

Results of Hyland et al. (2018)

Hyland et al. (2018), based on the work of Ruiter, Loyens and Paas (2017), investigated the relationships between spatial ability, interest in presented information, and task experience on the retention of novel information associated with fundamental engineering concepts. The methodology involved administering three validated psychometric tests of spatial ability to a cohort of university students, and analysing the results of these relative to Likert-type items concerning interest in pertinent content, perceived task experience, and performance in an immediate retention test of information presented in an authentic lecture. A number of statistically significant correlations were found including between spatial ability and performance on the retention test (r = .317, *p* = .004). The full correlation matrix is presented below (Table 1) in terms of the Spearman's rho coefficient as the majority of the data is ordinal.

Table 1. Correlation matrix from Hyland et al. (2018).

		1	2	3	4	5	6	7	8
1. Spatial ability	ρ	–							
	p								
2. Retention	ρ	.206	–						
	p	.062							
3. Interest	ρ	.103	.368**	–					
	p	.356	.001						
4. Attention	ρ	-.106	.120	.467**	–				
	p	.341	.280	.000					

		1	2	3	4	5	6	7	8
5. Effort focus	ρ	-.028	.051	.069	.028	–			
	p	.803	.647	.533	.801				
6. Effort understand	ρ	-.056	-.051	.178	.130	.650**	–		
	p	.613	.650	.107	.243	.000			
7. Lecture difficulty	ρ	-.187	-.216*	-.152	-.100	.058	.200	–	
	p	.091	.049	.169	.367	.600	.069		
8. Enjoyment	ρ	.135	.200	.505**	.315**	.136	.237*	-.040	–
	p	.225	.070	.000	.004	.220	.031	.719	
9. Question difficulty	ρ	.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).

Additionally, Hyland et al. (2018) conducted a stepwise multiple regression considering performance on the retention test as the dependant variable all of the other variables from the correlation matrix as independent variables. The final model was statistically significant, (F (3,79) = 8.916, $p < .000$) and accounted for 25.3% of the variance in knowledge retention. The results are shown in Table 2 below.

Table 2. Stepwise multiple regression from Hyland et al. (2018).

IV	Model 1			Model 2			Model 3		
	B	SE B	β	B	SE B	β	B	SE B	β
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^2		.138			.210			.253	
ΔF		12.915**			7.372**			4.510**	

Note: ** $p < 0.1$. Independent variables (IV): 1 = interest, 2 = spatial ability, 3 = question difficulty. Dependant variable = retention.

The results of this work were interesting in that spatial ability was found to account for an additional 7.2% of the variance in knowledge retention above and beyond participants' interest in the content. To investigate the generalisability of this result, this study employed a conceptual replication of Hyland et al. (2018). The differences in method include:

- The study cohort from Hyland et al. (2018) consisted of 83 students (69 males and 14 females, M_{age} = 18.19, SD_{age} = 1.18) studying on an engineering programme in an Irish University whereas the cohort from this study consisted of between 43 and 56 students (some participants missed testing sessions) studying on an engineering programme in an Irish Institute of Technology.
- The engineering content from Hyland et al. (2018) was associated with permanent and non-permanent methods of mechanical joining, whereas in this study the content was associated with gears.
- There were different lecturers delivering the content in both studies, however in both cases it was the students regular lecturer.

Aside from these variances the methods were identical. Full details of the method used in this study are presented below.

Method

Participants

The study was conducted with a 1st year cohort of engineering education students. A total of 76 students were invited to voluntarily engage with this study as part of their common engagement with an introductory module focussing on engineering mechanics. Participation required attending two testing sessions, each lasting one hour. A total of 56 students participated in the first session where they completed a battery of spatial tests. A total of 45 students participated in the second session where they engaged with a short declarative lecture, responded to Likert-type items associated with their experience of the lecture, and completed a retention test. In total, 43 students attended both sessions ($M_{age} = 20.91$, $SD_{age} = 5.95$) and of these 41 were male and 2 were female.

Instruments

Three psychometric tests of spatial ability were administered to participants. From the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976) the Paper Folding Test (PFT) and the Surface Development Test (SDT) were used. Additionally, the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) (Bodner & Guay, 1997; Guay, 1977) was used as it has been shown to be psychometrically sound specifically with engineering students (Maeda, Yoon, Kim-Kang, & Imbrie, 2013). These three tests were used as they each require a different cognitive action (i.e. mental folding, surface development, and mental rotations) and therefore through their combination, task related bias is reduced.

Participants also engaged with an experimental lecture. This was delivered for a period of 30 minutes by their regular lecturer. The content was new for all participants when considered as part of their formal undergraduate education. The lecture focused on mechanics, specifically gear trains, gear ratios and types of gears. 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 13 multiple part recall questions with a total of 24 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; “What two things can gears change in a gear train”. 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.

In this study, task experience was explored based on the variables examined by Ruiter et al. (2017) which included self-reported interest in the lecture content, attention, investment to stay focused, effort required to understand the lecture content, lecture difficulty, enjoyment and post-lecture question of difficulty. A 9-point Likert-type question based on the Paas (1992) Cognitive Load Rating Scale was used to represent the above variables. For example, for self-reported attention participants were asked to “Rate the level of interest you have in the lecture content” on a 9-point Likert-type scale from “very, very low interest” to “very, very high interest”.

Implementation

The first phase of the study involved participants attending a testing session where the three psychometric tests of spatial ability were administered. This was implemented within the participants’ regular lecture theatre. The session lasted for one hour, with six minutes allocated for the PFT, twelve minutes for the SDT and finally twenty minutes for the PSVT:R in line with their standard administration guidelines.

In the second phase of the study, participants engaged in the experimental lecture and knowledge retention test. This was administrated three weeks after the psychometric tests by the students' regular lecturer. Directly after the lecture two researchers distributed the knowledge retention test. The participants engaged in 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 first, which was immediately followed by the knowledge retention questions and the final Likert-type item concerning post-lecture question difficulty.

Results

Descriptive statistics for each of the variables examined in this study are presented in Table 3. Skewness and kurtosis values for all tests were within acceptable limits of between ±2 (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006).

The three psychometric tests of spatial ability all correlated positively with each other (average $r = .527$, $p < .01$). A factor analysis was conducted with the three psychometric tests as variables and the first factor accounted for a large proportion of the variance (68.63%) with factor loading ranging from .595 to .871. 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 4. 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 ($r = .379$, $p = .012$, n = 43) was observed.

Table 3. Descriptive statistics.

	N	Min	Max	M	SD	Skewness	Kurtosis
PFT	56	4	19	11.429	3.607	.274	-.672
SDT	56	5	60	37.143	15.182	-.480	-.805
PSVT:R	56	6	30	20.554	5.556	-.631	.345
Retention	45	7	23	15.556	4.132	-.402	-.507
Interest	43	1	9	6.628	1.398	-1.483	.709
Attention	43	3	9	6.093	1.231	-.265	.316
Effort focus	43	2	9	5.651	1.494	.097	.344
Effort understand	43	2	9	5.860	1.407	.205	1.335
Lecture difficulty	43	3	9	5.093	1.461	.264	-.253
Enjoyment	43	3	8	6.000	1.175	-.554	-.317
Question difficulty	42	2	7	4.881	1.383	-.416	-.701

Table 4. Spearman's Rho correlation matrix (n = 40-56).

		1	2	3	4	5	6	7	8
1. Spatial ability	ρ	–							
	p								
2. Retention	ρ	.372*	–						
	p	.014							
3. Interest	ρ	.317*	.400**	–					
	p	.044	.008						

		1	2	3	4	5	6	7	8
4. Attention	ρ	.106	.288	.618**	–				
	p	.509	.061	.000					
5. Effort focus	ρ	-.210	-.201	.218	.286	–			
	p	.187	.196	.161	.063				
6. Effort understand	ρ	-.190	-.094	.265	.426**	.577**	–		
	p	.235	.550	.086	.004	.000			
7. Lecture difficulty	ρ	-.279	-.095	-.142	.065	.278	.387*	–	
	p	.078	.543	.363	.681	.072	.010		
8. Enjoyment	ρ	.094	.180	.451**	.374*	.174	.429**	.069	–
	p	.560	.247	.002	.013	.263	.004	.659	
9. Question difficulty	ρ	.230	-.307*	-.057	-.056	.162	.134	.226	.053
	p	.153	.048	.722	.728	.312	.404	.155	.742

Note. **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

A total of 11 statistically significant correlations were observed in the data, 8 of which replicated the findings of Hyland et al. (2018). These include the correlations between spatial ability and retention (r = .379, p = .012) which is of particular interest as the purpose of this study was to collect data to confirm the relationship between these variables. Additionally, the correlations between retention and interest in the lecture content (ρ = .400, p = .008), the perceived amount of attention paid and interest (ρ = .618, p < .000), retention and perceived question difficulty (ρ = -.307, p = .088), enjoyment and interest (ρ = .451, p = .002), enjoyment and attention paid (ρ = .374, p = .013), effort required to stay focused and to understand the content (ρ = .577, p < .000), and enjoyment and the amount of effort perceived to be required to understand the content (ρ = .429, p = .004) were also found to replicate.

Finally, a multiple linear regression analysis was conducted with the performance in the retention test considered as the dependant variable, and interest in the lecture content, spatial ability, and perceived question difficulty entered as independent variables. The model was statistically significant (F (3,35) = 5.856, p = .002) with the independent variables collectively accounting for 33.4% of the variance in knowledge retention. Both interest in the content and spatial ability were significant predictors in the model (p < .05), and spatial ability accounted for 4.8% of the variance in knowledge retention, however this was not a significant change (p = .134)

Conclusion

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 replicated those of Hyland et al. (2018) in this regard, and add further credibility to the evidence suggesting that spatial ability does relate to knowledge retention. Considering that this result replicated, this suggests that one element of the causal relationship between spatial ability and performance in STEM education in that spatial ability has a positive impact on learning, over and above student interest, due to its predictive capacity for knowledge retention.

To conclude, the results of this study infer two primary recommendations for practice. First, student interest is a key factor in their retention of knowledge in the short term. The results do not permit the recommendation of any particular pedagogical approaches, but they do allow for the recommendation that educators clearly convey the importance and relevance of knowledge learning outcomes to students in an attempt to foster internal interest among them. Second, the understanding that spatial ability has an impact on knowledge retention provides evidence which can be used to inform spatial training interventions and future research. Critically, this result suggests a foundational association at a cognitive level adding validity to the effects seen through interventions. It also means that effort should continue to be focussed on developing such interventions from a foundational perspective to train spatial ability, and that activities associated with knowledge retention, such as n-back training, may provide additional effects if integrated into currently validated interventions.

References

Alias, M., Black, T., & Gray, D. (2002). Effect of instructions on spatial visualisation ability in civil engineering students. *International Education Journal*, *3*(1), 1–12.

Bodner, G., & Guay, R. (1997). The purdue visualization of rotations test. *The Chemical Educator*, *2*(4), 1–17.

Buckley, J. (2018). *Investigating the role of spatial ability as a factor of human intelligence in technology education: Towards a causal theory of the relationship between spa*. KTH Royal Institute of Technology.

Buckley, J., Seery, N., & Canty, D. (2018). Investigating the use of spatial reasoning strategies in geometric problem solving. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-018-9446-3

Carbonell Carrera, C., Saorín Pérez, J. L., de la Torre Cantero, J., & Marrero González, A. M. (2011). Engineers' spatial orientation ability development at the european space for higher education. *European Journal of Engineering Education*, *36*(5), 505–512.

Ekstrom, R., French, J., Harman, H., & Derman, D. (1976). *Kit of factor-referenced cognitive tests*. Princeton, New Jersey: Educational Testing Service.

Gravetter, F., & Wallnau, L. (2014). *Essentials of statistics for the bevahioural sciences*. California: Wadsworth.

Guay, R. (1977). *Purdue spatial visualization test: Rotations*. West Lafayette, Indianna: Purdue Research Foundation.

Hambrick, D., Libarkin, J., Petcovic, H., Baker, K., Elkins, J., Callahan, C., … LaDue, N. (2012). A test of the circumvention-of-limits hypothesis in scientific problem solving: The case of geological bedrock mapping. *Journal of Experimental Psychology: General*, *141*(3), 397–403.

Hyland, T., Buckley, J., Seery, N., Power, J., & Gordon, S. (2018). Investigating the Relationships between Spatial Ability, Interest, and Task Experience on Knowledge Retention in Engineering Education. In *In N. Seery, J. Buckley, D. Canty, & J. Phelan (Eds.), PATT2018: Research and Practice in Technology Education: Perspectives on Human Capacity and Development. Westmeath, Ireland: Athlone Institute of Technology* (pp. 263–269).

Kirschner, P., Sweller, J., & Clark, R. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86.

Lin, H. (2016). Influence of design training and spatial solution strategies on spatial ability performance. *International Journal of Technology and Design Education*, *2016*(1), 123–131.

Lohman, D. (1996). Spatial ability and g. In I. Dennin & P. Tapsfield (Eds.), *Human Abilities: Their Nature and Measurement* (pp. 97–116). New Jersey: Lawrence Erlbaum Associates.

Maeda, Y., Yoon, S. Y., Kim-Kang, G., & Imbrie, P. K. (2013). Psychometric properties of the revised PSVT:R for measuring first year engineering students' spatial ability. *International Journal of Engineering Education*, *29*(3), 763–776.

Mayer, R. (2002). Rote versus meaninful learning. *Theory into Practice*, *41*(4), 226–232.

Onyancha, R., Derov, M., & Kinsey, B. (2009). Improvements in Spatial Ability as a Result of Targeted Training and Computer-Aided Design Software Use: Analyses of Object Geometric and Rotation Types. *Journal of Engineering Education*, *98*(2), 157–167.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving Skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, *84*(4), 429–434.

Ramey, K., & Uttal, D. (2017). Making sense of space: Distributed spatial sensemaking in a middle school summer engineering camp. *Journal of the Learning Sciences*, *26*(2), 277–319.

Ruiter, M., Loyens, S., & Paas, F. (2017). The effects of cycling on a desk bike on attention, retention and mood during a video lecture. *Applied Cognitive Psychology*, *31*(6), 593–603.

Simon, H. A. (1978). Information-processing theory of human problem solving. *Handbook of Learning and Cognitive Processes*, *5*, 271–295. https://doi.org/10.4324/9781315770314

Sorby, S. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal*, *63*(2), 21–32.

Sorby, S. (2009a). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, *31*(3), 459–480.

Sorby, S. (2009b). Educational Research in Developing 3 - D Spatial Skills for Engineering Students Educational Research in Developing 3-D Spatial Skills for Engineering, (September 2014), 37–41. https://doi.org/10.1080/09500690802595839

Sorby, S., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, *26*(1), 20–29.

Stieff, M., & Uttal, D. (2015). How much can spatial training improve STEM achievement? *Educational Psychology Review*, *27*(4), 607–615.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. New York: Springer.

Terrell, M. (2006). Anatomy of learning: Instructional design principles for the anatomical sciences. *The Anatomical Record (Part B: The New Anatomist)*, *289*(B), 252–260.

Trochim, W., & Donnelly, J. (2006). *The research methods knowledge base*. Ohio: Atomic Dog Publishing.

Uttal, D., Meadow, N., Tipton, E., Hand, L., Alden, A., Warren, C., & Newcombe, N. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352–402.

Wai, J., Lubinski, D., & Benbow, C. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*(4), 817–835.