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

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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_{age} = 18.19, SD_{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 ± 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	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					
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).

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 (ρ = .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 (ρ = .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	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.

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 (β = .355) than spatial ability (β = .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 (ρ = -.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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