AN EXPLORATORY STUDY INTO THE COGNITIVE AND BEHAVIOURAL INFLUENCES ON PROBLEM SOLVING PERFORMANCE

J. Buckley[1], U. Howley[1] and N. Seery[1],

1. Department of Design and Manufacturing Technology, University of Limerick, Ireland.

ABSTRACT

It is widely accepted that spatial cognition plays a critical role in STEM educational success. However, while this relationship has shown to relate to educational factors such as success and retention, it does not offer any insight into the nature of the learning experience received by students or of any associated problem solving behaviours. This exploratory study was designed to examine the potential relationship between both cognitive factors and behavioural factors within problem solving. The study was conducted with a cohort of Initial Technology Teacher Education students (n=10) and utilised a battery of spatial skills psychometric tests as well as a series of experimentally designed physical tasks. A think-aloud protocol was employed during the physical tasks to elicit better insights into the behavioural factors involved. Findings illustrate the potential impact that emotions and task inherent feedback can have on performance as well as identifying the use of heuristics in problem solving. This is then discussed in terms of their implications for future research and STEM educational practices.

KEYWORDS: Spatial Ability, Mental Rotations, STEM Education

1. INTRODUCTION

The correlation between spatial ability and success in STEM education is one of the most regularly cited correlations in pertinent educational research [1]. It is theorised that this stems from the nature of activities within the environment being associated with spatial reasoning. However, the cognitive faculty of spatial ability has been found to consist of multiple spatial factors [2, 3]. The specific factors which are typically associated with the correlation between spatial reasoning and success in engineering education involve mental rotation. However, these skills are typically measured using psychometric tests with educational success typically associated with exam performance. These measures align with the 'geographic' ontology for human intelligence research [4] which describes attempts to create a cognitive map of the mind using psychometrics.

Larson [5] argues that such measures aren't entirely representative of the dynamic 3-dimensional world in which people operate. Aligning with this, Sternberg [4] identifies the 'computational' ontology which examines intelligence from the perspective of behaviour. While both approaches individually have the capacity to offer extensive insight into STEM educational practices, this study aims to examine both simultaneously to examine the interplay between psychometric and behavioural factors impacting on STEM educational success.

2. MENTAL ROTATION FACTORS PERTINENT TO SPACE

The spatial skills framework conceptualised by Buckley and Seery [2, 3] includes three posited spatial factors pertinent to mental rotations. These include speeded rotation, spatial relations, and spatial orientation. Speeded rotation involves mentally rotating simple, often 2-dimensional objects about a single axis quickly and accurately and spatial relations requires the mental rotation of more complex 3-dimensional objects about one or more axes. Where speeded rotation is focussed on cognitive speed, spatial relations is associated with cognitive power [5] and therefore is less of focussed on time. Spatial orientation involves the ability to mentally change perspective in space as opposed to rotating the object itself.

There is a hypothesised relationship between speeded rotations and spatial relations as they both involve object-based transformations, with spatial orientation being differentiated by its reliance on egocentric and allocentric reasoning [6]. Moreau [7] demonstrated a potential link between speeded rotation and spatial relations through spatial ability training. Cognitive training associated with spatial relations improved both factors whereas training associated with speeded rotation improved only itself. Considering the geometry involved and the nature of the cognitive activity, a hierarchical relationship is posited to exist between these factors.

Hegarty and Waller [8] identified a dissociation between mental rotation and perspective taking abilities offering the conjecture that this is due to a difference between one’s ability to make egocentric spatial transformations and object-based transformations. This was supported by a previous study where it was found that the dominant strategy used to complete tests of spatial orientation was to imagine oneself egocentrically within the test environment [9]. Statistically significant correlations were found between mental rotation and perspective taking abilities which is the foundation for considering them all as involving mental rotations. The differentiation exists in the nature of the rotation being either of the object or the self.

3. METHOD

3.1. Approach and Participants

The purpose of this study was to examine mental rotation related spatial factors and behavioural factors when solving physical problems. To achieve this, a battery of psychometric spatial ability tests and a selection of physical tasks were administered to a cohort of Initial Technology Teacher Education (ITTE) students (n=10) of which one was female and 9 were male. The cohort had a mean age of 21 with a standard deviation of 0.894. Participation in this study was voluntary.

While the psychometric tests utilised were all well-established tests, the design of the physical tasks was experimental. For the purposes of this study, the physical problems were theorised to align with each of the three mental rotation factors previously discussed. They were also designed to be abstract in nature to allow for domain general behaviours to be observable so as to create a conceptual framework for a future investigation with domain specific problems. Gigerenzer [10] describes that the most interesting problems within the computational ontology are computationally intractable and have well defined rules and Sorby [11] describes evidence which suggests activities such as sketching, studying STEM related subjects, playing 3D video games and partaking in sports all contribute to improving spatial skills. Therefore the physical tasks were designed to align with such activities and have defined rules. A think-aloud protocol was implemented within the physical tasks to gather qualitative data.

3.2. Design and Implementation

The psychometric tests adopted for this study aligned with each of the three mental rotation factors. For the speeded rotation factor, the Cube Comparison Test (CCT) and Card Rotation Test (CRT) were utilised [12]. For spatial relations, the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R) [13] and Mental Rotations Test (MRT) [14] were used. For spatial orientation, the Perspective Taking/Spatial Orientation Test (PTSOT) [8] was used. The physical tasks designed for use within this study included:

- ***Tetris***: Each participant played a 2-dimensional version of Tetris for 15 minutes. The final score achieve was noted for each participant and the average score was considered as the performance measure
- ***Puzzles***: Three separate 3-dimensional puzzles were utilised. The solution was presented and participants were given the pieces which needed to be constructed into the solution. Ten minutes were afforded to each puzzle. Performance was denoted by the number of pieces correctly assembled
- ***Paths***: Twelve unique paths were created by a series of lines and points on the ground which incrementally increased in difficulty. The participant stood at the starting point and memorised the path presented to them. They were subsequently blindfolded and were required to walk along the path. The score received was the distance between the actual finishing point and where the participant finished
- ***Obstacles***: Ten configurations of obstacles were included in this task. Each configuration consisted of a series of horizontal poles at varying heights and distances from each other which needed to be stepped over. Similar to the 'paths' activity, participants were blindfolded and the configurations increased in difficulty. Participants were awarded one point for each pole successfully stepped over

4. FINDINGS

4.1. Quantitative Findings

Initially, a correlational analysis was conducted to identify any statistically significant correlations between measures (Table 1). Four correlations achieved statistical significance. The ‘puzzles’ task showed a high correlation with the MRT (r = .751, $p < 0.05$), the PSVT:R showed a high correlation with the PTSOT (r = .767, $p < 0.05$), the PTSOT showed a very high correlation with the CCT (r = .873, $p < 0.01$) and the ‘obstacles’ task correlated very highly with the ‘paths’ task (r = .889, $p < 0.01$).

Table 1. Correlation matrix for psychometric tests and physical tasks

		CRT	CCT	Tetris	PSVT:R	MRT	Puzzles	PTSOT	Paths
CCT	Pearson Correlation	.504							
	Sig. (2-tailed)	.167							
	N	9							
Tetris	Pearson Correlation	.384	.419						
	Sig. (2-tailed)	.307	.229						
	N	9	10						
PSVT:R	Pearson Correlation	.375	.512	-.159					
	Sig. (2-tailed)	.320	.159	.683					
	N	9	9	9					
MRT	Pearson Correlation	.055	.591	.279	.232				
	Sig. (2-tailed)	.888	.072	.435	.548				
	N	9	10	10	9				
Puzzles	Pearson Correlation	.138	.597	.378	.385	.751*			
	Sig. (2-tailed)	.723	.068	.281	.306	.012			
	N	9	10	10	9	10			
PTSOT	Pearson Correlation	.559	.873**	.303	.767*	.534	.575		
	Sig. (2-tailed)	.118	.002	.428	.016	.139	.105		
	N	9	9	9	9	9	9		
Paths	Pearson Correlation	.048	-.150	-.197	-.395	.166	.033	-.159	
	Sig. (2-tailed)	.903	.680	.585	.293	.647	.928	.683	
	N	9	10	10	9	10	10	9	
Obstacles	Pearson Correlation	.127	.164	.033	-.278	.495	.200	.164	.889**
	Sig. (2-tailed)	.774	.650	.928	.468	.146	.580	.673	.001
	N	9	10	10	9	10	10	9	10

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

4.2. Qualitative Findings

In addition to the quantitative results, the think-aloud protocol transcriptions were analysed to discern any behavioural factors which may have impacted on performance within the physical tasks. A number of interesting insights emerged from this analysis. In particular, emotions, responses to feedback within the task, and heuristics employed were observable from the analysis. An example of a potential emotional influence is observable through Participant 3’s engagement with the ‘puzzles’ task. The task was identified as “really difficult” and over time became “very frustrating”, however when they did fit pieces together they were “satisfied”. During this task Participant 3 also employed the “trial and error” heuristic to solving problems and tried to “make sense” of the geometry by “playing around with it”.

Feedback was a critical feature of the physical tasks that wasn’t available in the psychometric tests. In the ‘paths’ task Participant 3 began by referring to distances in terms of psychophysical measurements such as a “normal step” and “slightly bigger step”. Over time these became more accurate. The length of a ‘step’ became a more explicit unit of measurement which was seen through the judgment of a distance of “two and a half of my steps”. Participant 4 offered similar commentary regarding emotions and heuristics, however of most interest was the clear identification of the role of feedback within the tasks as “I hit it with my right hand the last time, so I’m gonna keep my arms closer, and bring myself slightly to the left”.

5. DISCUSSION AND CONCLUSION

The results of this study offer interesting insights into the consideration of both psychometric results and human behaviour within problem solving and these can be directly transferred into STEM educational practices. As previously discussed, psychometric results are often correlated with exam performance in the discipline however these does not necessarily reflect the learning experience received by the student. As problem-based learning (PBL) is a pedagogical approach popular within STEM education [15], the role of emotions, the nature of heuristics employed, and the effect that task related feedback play in such learning experience merit further research and practitioner recognition. Interestingly, the highest correlation between all tasks was seen between the ‘paths’ and ‘obstacles’ tasks and it is posited that this is due to their methodological similarity in the immediate direct feedback which participants received. This also provides an interesting lens to look at both educational and cognitive assessment from.

Novick and Bassok [16] describe how research into problem solving behaviours has evolved from examining domain general to domain specific heuristics which is a critical direction for the progression of this research. The amalgamation of the geographic and computational ontologies to create a methodology for examining ecological problem solving within STEM educational environments has the potential to significantly inform pedagogical practices. The behavioural results of this study are corroborated by Willis et al [17] who identify that a person’s emotions can influence a person’s true expression of intelligence. Therefore for subsequent work and pedagogical practices it is imperative that the experience of the student is captured and acknowledged.

6. REFERENCES

[1] J. Wai, D. Lubinski, and C. Benbow, Spatial Ability for STEM Domains: Aligning over 50 years of Cumulative Psychological Knowledge Solidifies its Importance, *J. Educ. Psychol.* Vol.101 (2009) 817-835.

[2] N. Seery, J. Buckley and T. Delahunty, Developing a Spatial Ability Framework to Support Spatial Ability Research in Engineering Education, in B. Bowe (ed.). *Proc. 6th REES*, Dublin, 2015.
[3] J. Buckley and N. Seery, Framing Spatial Cognition: Establishing a Research Agenda, in L. Sun, H. Steinhauer and D. Lane (eds.). *Proc. ASEE EDGD 70th Mid Year*, Daytona Beach, Florida, 2016, 118–122.
[4] R. Sternberg, The Concept of Intelligence, in R. Sternberg (ed.). *Handbook of Intelligence*, Cambridge, (2000), 3–15.
[5] G. Larson, Mental Rotation of Static and Dynamic Figures, *Percept. Psychophys.* Vol.58 (1996), 153–159.
[6] R. Klatzky, Allocentric and Egocentric Spatial Representations: Definitions, Distinctions and Interconnections, in C. Freksa, C. Habel and K. Wender (eds.). *Spatial Cognition: An Interdisciplinary Approach to Representing and Processing Spatial Knowledge*, Berlin, 1998, 1-17.
[7] D. Moreau, Differentiating Two- from Three-Dimensional Mental Rotation Training Effects, *Q. J. Exp. Psychol.* Vol.66 (2013), 1399–1413.
[8] M. Hegarty and D. Waller, A Dissociation Between Mental Rotation and Perspective-Taking Spatial Ability, *Intell*. Vol.32 (2004), 175–191.
[9] M. Kozhevnikov and M. Hegarty, A Dissociation Between Object Manipulation Spatial Ability and Spatial Orientation Ability, *Mem. Cognition*, Vol.29 (2001), 745–756.
[10] G. Gigerenzer, Why Heuristics Work, *Perspect. Psychol. Sci.* Vol.3 (2008), 20–29.
[11] S. Sorby, Developing 3-D Spatial Visualization Skills, *Eng. Des. Graph. J*. Vol.63 (1999), 21–32.
[12] R. Ekstrom, J. French, H. Harman and D. Derman, *Kit of Factor-Referenced Cognitive Tests*, Educational Testing Service, New Jersey, (1976).
[13] R. Guay, *Purdue Spatial Visualization Test: Rotations*, Purdue Research Foundation, Indianna, (1977).
[14] S. Vandenberg and A. Kuse, Mental Rotations, A Group Test of Three-Dimensional Spatial Visualization, *Percept. Mot. Skills*, Vol.47 (1978), 599–604.
[15] R. Lynch, P.M. McNamara and N. Seery, Promoting Deep Learning in a Teacher Education Programme through Self- and Peer-Assessment and Feedback, *Euro. J. Teacher Ed*. Vol.35 (2012), 179–197.
[16] L. Novick and M. Bassok, Problem Solving, in K. Holyoak and R. Morrison (eds.). *The Cambridge Handbook of Thinking and Reasoning*, Cambridge University Press, Cambridge, (2005), 321–349.
[17] J. Willis, R. Dumont and A. Kaufman, Factor-Analytic Models of Intelligence, in R. Sternberg and S. B. Kaufman (eds.). *The Cambridge Handbook of Intelligence*, Cambridge University Press, Cambridge, (2011), 39–57.