Conceptualization in Visuospatial Reasoning Tasks: A Research Direction

Thomas Delahunty & Dr. Niall Seery
Department of Design and Manufacturing Technology
University of Limerick

Dr. Raymond Lynch
Department of Education and Professional Studies
University of Limerick

Abstract

Visuospatial skills are a critical component of problem solving within graphical education. Despite this importance, evidence exists to suggest deficiencies in students' reasoning abilities within graphical education in Ireland. The research presented in this paper delineates an initial exploration of problem conceptualization within the area of graphical education. Participants were asked to solve a typical graphical task while electroencephalographic data was recorded in order to track conceptualization processes. Findings indicate the possibility of multiple conceptualizations for a typical task which may provide further insight regarding issues of visuospatial reasoning abilities within graphical education. The study concludes with a number of possible research questions for future work.

Introduction

The critical role of robust visuospatial skills in problem solving and reasoning tasks is well documented in the literature. The work of Sorby (2005, 2009) has shown the benefits of enhancing spatial abilities in terms of success in a wide variety of University courses such as calculus and chemistry where visualization ability is a valuable aid in thinking and reasoning. Visuospatial skills are not just important in discipline specific contexts but also for a wide variety of human endeavors such as navigation, planning and even inference and deduction (Tversky 2005, 2011).

Graphical education is one of the subject disciplines where developing visuospatial competencies is a core focus. Despite this, previous research by Delahunty et al. (2013) has raised concerns regarding the approaches students took to problem solving within visuospatial graphical tasks. In this particular study, student teachers were tasked with solving an applied analytical problem. Prior to completing this problem students completed a stage of knowledge acquisition where the associated learning focus was directly relevant to the applied task. The participants displayed a wide variety of approaches to the applied problem (see figure 1) with some being more effective than others.

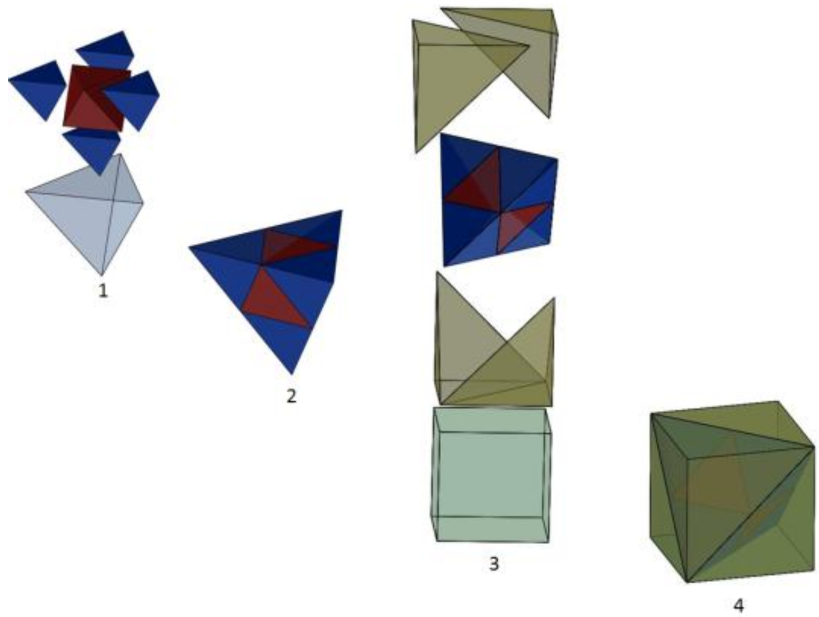

Figure 1: Applied Analytical Task Used by Delahunty et al. (2013)

The high number of ineffective approaches to the task, observed during this study, could be due to a number of underlying causes. Two different areas of concern are hypothesized to be of primary interest within the context of this research. One of the areas could be that of transfer where students are having difficulty applying previously learned knowledge to a novel situation (Bransford and Schwartz 1999, Thorndike and Woodworth 1901). The second area of interest is conceptualization. This area is critical for effective problem solving and reasoning and is often overlooked in research focused on problem solving (Clement 2000, Goméz et al. 2000). The research discussed in this paper will concentrate on this area of conceptualization as issues of transfer have been rigorously investigated by previous authors (Bransford and Schwartz 1999, Greeno 2006, Thorndike and Woodworth 1901).

Conceptualization

Conceptualization is a diverse area but is known to be an extremely important component of the problem solving process. Goméz et al. (2000) describe conceptualization as *"modeling by the problem solver"*. This modelling process results in the formation of a "*conceptual model"* for that problem (Duit and Treagust 2012). However, it should be noted that there are a number of different conceptual models, which can be constructed for a particular problem (Adams 2001). This is not surprising given the different background knowledge and experience that students bring to the situation.

Conceptualization is posited to comprise of two distinct phases, analysis and synthesis (Goméz et al. 2000). Analysis is a regressive process where the problem is broken down and understood and involves elements of problem representation that is best described as a representation which solver's construct to summarize their understanding of the task (Duit and Treagust 2012, Novick and Bassok 2005). Synthesis is progressive in nature and allows all knowledge (representations) constructed in the analysis stage to be amalgamated and utilized to implement an approach (Goméz et al. 2000).

The most important characteristic of the area of conceptualization is the direct influence the solver's conceptualization has on the approach adopted to the task at hand (Adams 2001). This area is well studied within science education (Ozdemir and Clark 2007) but there exists a dearth in research within graphical problem solving contexts. This paper presents the first attempt in determining a relationship between conceptualization strategies and problem solving performance within a graphical education context.

As part of a larger research study currently underway at the University of Limerick, this paper will focus on conceptualization of typical graphical problems. Specifically this study will investigate whether typical graphical problems are conceptualized differently. Furthermore, it will explore the relationship between the conception and approach to the solving of the problem.

Method

The method employed within this study was centered on a typical graphical task which is commonly implemented within graphical education in Ireland. The task, which is shown in figure 2, is based on knowledge of skew lines and the oblique plane, which is a core topic within plane and descriptive geometry. The participants in the study were two postgraduate research students who had previously attained qualifications in graphical education.

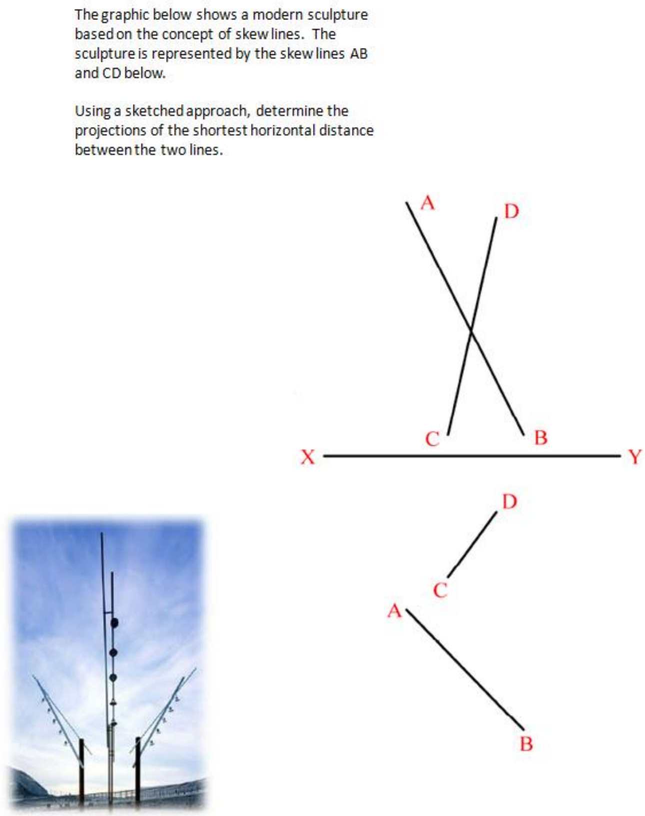

Figure 2: Skew Lines Task

In order to observe the style of cognitive activity occurring during the task, the participants were asked to wear an electroencephalographic (EEG) headset. This concept of using non-invasive EEG technology to monitor cognitive function was discussed by Delahunty et al. (2012). The use of EEG technology was shown to be applicable to educational research and is capable of highlighting underlying cognitive processes (Neill 2006). The headset used was developed by Emotiv technologies and is shown in figure 3. The headset consists of 14 sensors which are dispersed across the scalp in accordance with the international 10-20 system for electrode placement (Banich and Compton 2011). These sensors record electrical activity conducted in the cerebral cortex which is a rich source of data related to cognitive functioning (Rowan and Tolunsky 2003). The data recorded was processed using *eegLab* which is an open source tool for neuroscientific data analysis allowing statistical and graphical outputs (Delorme and Makeig 2004).

Figure 3: Emotiv EEG Headset

The implementation of the graphical problem and EEG recording procedure are depicted in figure 4. In addition to recording the EEG activity of the two participants a follow up discussion took place, post-task, in order to further qualify the data. Participants were asked if they would briefly describe the approach they took to solving the problem. The purpose was to explore if there were different conceptions of the task and if there existed a relation between the conceptualization constructed by the participant and the effectiveness of the consequent approach.

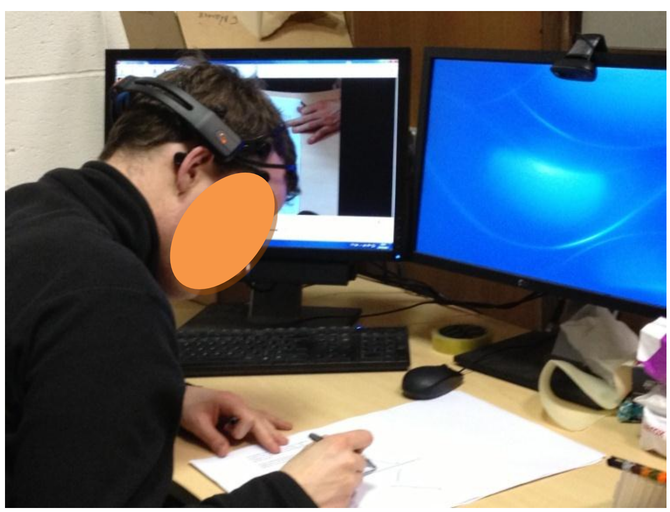

Figure 4: Participant 01 Attempting Task

Findings

EEG data is typically analyzed in different frequency bands which have been shown to be correlated with different styles of cognitive activity such as convergent/divergent thinking and memory (Molle et al. 1999, Osaka 1984). The frequency band of interest in this initial exploration of conceptualization is the Beta band which has been shown to be widely associated with cognitive functions such as visualization (Razoumnikova 2000, daSilva 2010). The graphical outputs for both participants' EEG measurements displaying the Beta power dispersion are shown in figures 5 and 6.

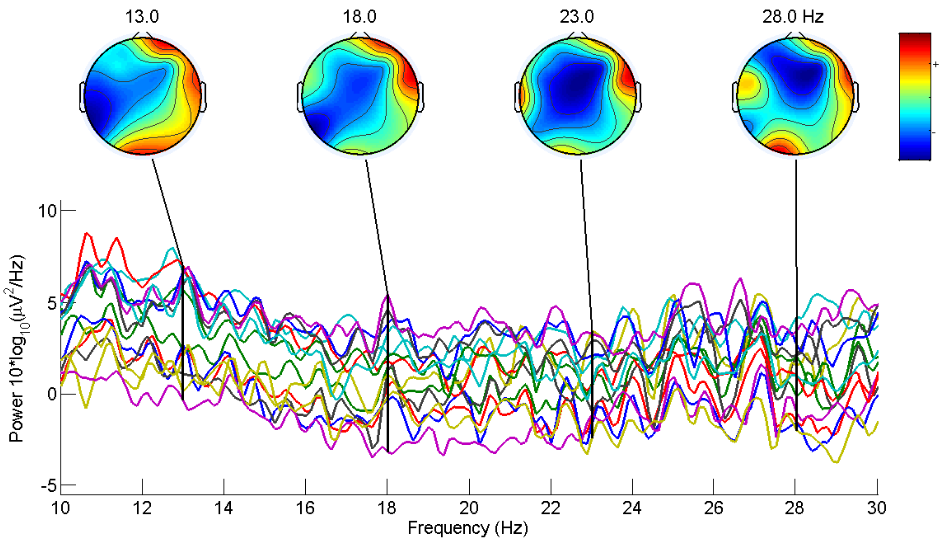

Figure 5: Participant 01 Beta Power Dispersion

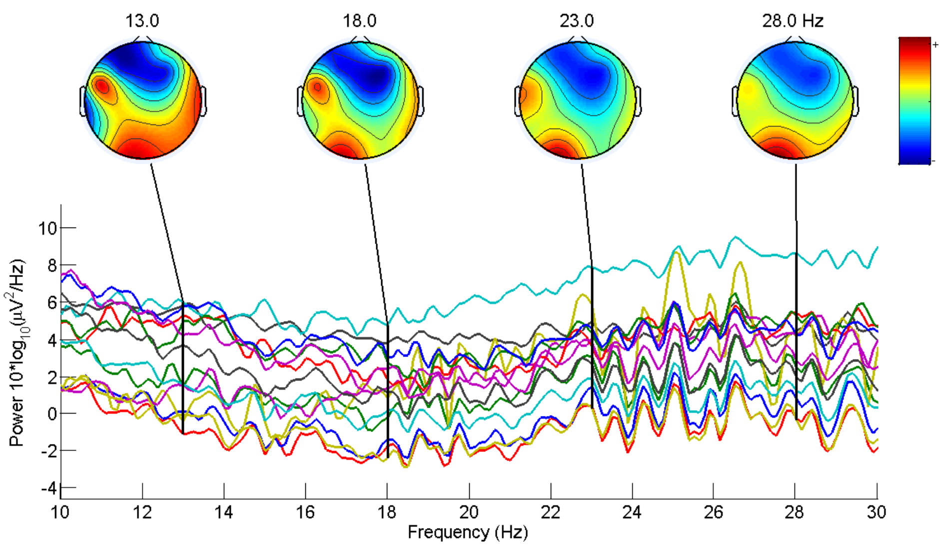

Figure 6: Participant 02 Beta Power Dispersion

As can be seen in the above figures there are two different patterns of activation occurring for each participant. As a brief comparison, it can be seen that participant 02 (figure 6) exhibited a more typical activation of someone who attempted to visualize the problem with more occipital activation. Participant 01(figure 5) showed more activation in frontal and temporal areas. The data seems to indicate two different approaches to this problem.

To clarify the approaches participants were asked to describe their approach to the task. Participant 01 described his approach as focusing on the lines as two dimensional entities and attempted to recall the steps in a logical fashion. On the other hand, participant 02 described his approach as one focused on visualizing the skew lines as a three dimensional concept and trying to implement a solution by working back.

Participant 01 (figure 5) conceptualized the problem as two-dimensional entities and was able to utilize a memorized strategy to complete a solution. The temporal and frontal activations, typically associated with memory functions (Banich and Compton 2011), evidenced in figure 5 and this participant's description of problem solving approach corroborate this finding.

In contrast, participant 02 displayed an activation more typically associated with visual strategies involving the occipital area of the cortex (Ward 2010). His description of approach correlated with this finding as he conceptualized the task as three-dimensional lines and attempted to implement a solution by working back. The most interesting finding though is the fact that participant 01 was the only one to display a correct solution.

Conclusions and Future Research

The research presented here attempted to ascertain whether a typical graphical task can be conceptualized differently by participants of similar expertise and the findings indicate that this is indeed the case. As can be seen the EEG methodology combined with post-task interview support this finding.

The unexpected finding was that participant 02, despite having conceptualized and approached the problem as one would expect a graphical educator to do, did not solve it. Participant 01 conceptualized the task alternatively, as two dimensional, which may have allowed him easier access to long-term memory and consequently solved the problem. It should be emphasized that this study is only the first exploration into this area and it has raised significant questions:

1. What is the relationship between knowledge acquisition and conceptualization abilities within graphical problem solving?
2. Is there a relation between a problem solver's visualization ability and their ability to successfully conceptualize these types of graphical tasks?
3. Are the tasks currently utilized within graphical education in Ireland catering for the development of effective conceptualization skills?
4. Are there alternative methods of conceptualizing a typical graphical problem which may be more effective for solving the said problem?

References

Adams, J. L. (2001) *Conceptual Blockbusting: A Guide to Better Ideas*, 4th ed., Cambridge, Massachusetts: Perseus Publishing.

Banich, M. T. and Compton, R. J. (2011) *Cognitive Neuroscience*, Wadsworth, USA: Cengage.

Bransford, J. D. and Schwartz, D. L. (1999) 'Rethinking Transfer: A simple protocol with multiple implications', *Review of Research in Education*, 24, 61-100.

Clement, J. (2000) 'Model based learning as a key research area for science education', *International Journal of Science Education*, 22(9), 1041-1053.

daSilva, F. L. (2010) 'EEG: Origin and Measurement' in Mulert, C. and Lemieux, L., eds., *EEG-fMRI*, Berlin: Springer.

Delahunty, T., Seery, N. and Lynch, R. (2012) 'Examining Neuronal Function during the Completion of Established Graphical Tasks', in *Engineering Design Graphics Division 67th Mid Year Conference*, Limerick, Ireland, 22-25.

Delahunty, T., Seery, N., Lynch, R. and Lane, D. (2013) 'Investigating Student Teachers' Approach to Solving Applied Analytical Graphical Problems', *Engineering Design Graphics Journal*, 77(1), 5-22.

Delorme, A. and Makeig, S. (2004) 'EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis', *Journal of Neuroscience*, 134, 9-21.

Duit, R. and Treagust, D. F. (2012) 'How Can Conceptual Change Contribute to Theory and Practice in Science Education?' in Fraser, B. J., Tobin, K. and McRobbie, C. J., eds., *Second International Handbook of Science Education*, New York: Springer, 107-118.

Goméz, A., Moreno, A., Pazos, J. and Sierra-Alonso, A. (2000) 'Knowledge maps: An essential technique for conceptualisation', *Data and Knowledge Engineering*, 33, 169-190.

Greeno, J. G. (2006) 'Authoritative, Accountable Positioning and Connected, General Knowing: Progressive Themes in Understanding Transfer', *The Journal of the Learning Sciences*, 15(4), 537-547.

Molle, M., Marshall, L., Wolf, B., Fehm, H. L. and Born, J. (1999) 'EEG complexity and performance measures of creative thinking', *Psychophysiology*, 36, 95-104.

Neill, M. G. (2006) *Human Neuropsychology*, 2nd ed., Harlow: Prentice Hall.

Novick, L. R. and Bassok, M. (2005) 'Problem Solving' in Holyoak, K. J. and Morrison, R. G., eds., *The Cambridge Handbook of Thinking and Reasoning*, New York: Cambridge University Press, 321-369.

Osaka, M. (1984) 'Peak Alpha Frequency of EEG during a Mental Task: Task Difficulty and Hemispheric Differences', *Psychophysiology*, 21(1), 101-105.

Ozdemir, G. and Clark, D. B. (2007) 'An Overview of Conceptual Change Theories', *Eurasia Journal of Mathematics, Science and Technology Education*, 3(4), 351-361.

Razoumnikova, O. M. (2000) 'Functional organization of different brain areas during convergent and divergent thinking: an EEG investigation', *Cognitive Brain Research*, 10, 11-18.

Rowan, A. J. and Tolunsky, E. (2003) *Primer of EEG*, Pennsylvania: Butterworth Heinemann.

Sorby, S. (2009) 'Educational Research in Developing 3-D Spatial Skills for Engineering Students', *International Journal of Science Education*, 31(3), 459-480.

Thorndike, E. L. and Woodworth, R. S. (1901) 'The influence of improvement in one mental function on the efficiency of other mental functions', *Psychological Review*, 8, 247-261.

Tversky, B. (2005) 'Functional Significance of Visuospatial Representations' in Shah, P. and Miyake, A., eds., *The Cambridge Handbook of Visuospatial Thinking*, New York: Cambridge University Press.

Ward, J. (2010) *The Student's Guide to Cognitive Neuroscience*, 2nd ed., East Sussex: Psychology Press.