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Spatial Skills and Success in Engineering Education: A Case for Investigating Etiological Underpinnings

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Abstract

One of the most consistent findings within engineering education research is the relationship between spatial skills achievement and success within STEM disciplines. A critical dearth in this research area surrounds the question of causality within this known relationship. Investigating the etiological underpinnings of the association of spatial skills development to success in engineering education is a contemporary research agenda and possesses significant implications for future practice. This paper presents a starting point through a review of some of the pertinent literature to consider this current agenda.

Introduction

One of the most widely established research findings within engineering education research is the relationship between heightened spatial skills and success among students. Research by Sorby (2007, 2009) has consistently demonstrated significant gains in performance across different domains of STEM learning as a result of students' participation in a targeted spatial skills intervention. Although, the relationship is widely established and repeatedly demonstrated, the precise etiological foundations of the relationship are not well explored (Seery et al. 2015). This may be a limiting factor in the acknowledgement of the fundamental importance of spatial skills to the development of future engineering graduates. Bodies such as the National Science Board (NSB) have made the case for STEM talent among those individuals with high aptitudes in verbal, mathematical *and* spatial skills (NSB 2010). Understanding the causal relationship(s) between spatial skills and success in engineering education may strengthen the rationale for the focus on developing high-level spatial skills among students. This paper represents a starting point in this investigation and looks to explore some of the key rationales for understanding the causality of the relationship between spatial skills achievement and success in engineering education.

Spatial Ability and Performance in Engineering Education

It has been widely established that improving spatial skills among engineering students has significant benefits for a variety of aspects of their study. In an extensive meta-analytic study, Uttal et al. (2013) demonstrated that generally spatial skills training results in an improvement (equating to an effect size of 0.47) in spatial ability. This demonstrates that spatial skills can be effectively learned and have the potential to facilitate significant gains in learning within engineering (Uttal et al. 2013).

The exact causal nature of this association is not well understood and there are only limited hypotheses currently that explore this. For example, spatial visualization skills are necessary for developing 3-D CAD expertise (Sorby 2000). Branoff and Dobelis (2014) have investigated this relationship further and have found that spatial visualization plays a key role in the quality of CAD modelling strategies students adopt when operating CAD software. The ability to visualize has also been discussed as an important component of "designerly" thinking (Kimbell and Stables 2008). Given the large amount of divergent design processes evident in engineering disciplines it is apparent that spatial visualization has a role to play in this activity.

A less obvious area where spatial visualization skills are hypothesized to be advantageous is in problem solving. Tversky (2005) posits that possessing advanced spatial skills allows an individual to construct robust mental representations of problems. These representations are known to be critical in solving all manners of problems but particularly in the case of "insight" problems where overcoming an impasse is necessary (Ollinger and Goel 2010, Pretz et al. 2003). Dealing with an impasse in a problem often necessitates re-representing the problem situation so that a different approach may be adopted.

Given the brief evidence presented in this section it is possible that the role of spatial skills in engineering education performance is multi-faceted. It is at this stage necessary to consider in short the construct of spatial skills and examine the difficulties of determining the causal relationship between spatial skills and engineering education performance.

Construct and Issues of Causality

Spatial skills are a vast and complex construct, which encompasses several different elements known as spatial factors (McGee 1979). A number of different spatial factors have been identified by various researchers such as Lohman (1979) who proposed the existence of three different spatial factors, Spatial Visualization, Spatial Relations and Spatial Orientation. There have been a number of debates surrounding the specific nature of various spatial factors that have been proposed over the years. As a result there is no agreement as to which specific factors constitute spatial skills (Uttal et al. 2013). However, within the pertinent literature there is some general agreement that the factor of spatial visualization does constitute a significant component of spatial cognition (McGee 1979, Pittalis and Christou 2010, Pellegrino et al. 1984). Additionally, Uttal et al. (2013) have demonstrated that spatial visualization transfers well to other spatial factors following targeted interventions. Given the contentious history surrounding attempts to develop a unified definition of spatial skills, it is not surprising that determining a casual underpinning has been so obstinate. Recent work by Seery et al. (2015) has begun developing a comprehensive spatial factors framework with the objective of presenting a unified and coherent definition of spatial abilities.

As well as the debates surrounding the exact definition of spatial skills there are also various methodological limitations in studies investigating the relationship between spatial skills and STEM success. This work provides a comprehensive taxonomy of spatial factors from which we can begin to consider the etiological role spatial cognition has in engineering education success.

Another issue cited by Uttal and Cohen (2012) is that of the "third variable" problem that appears in many of the correlational studies on spatial skills and success in STEM disciplines. This refers to studies, which have found a significant relationship but have failed to control for several other variables that have also been shown to contribute to performance in STEM education such as mathematical ability (Uttal and Cohen 2012). Making this issue even more problematic is the role that spatial abilities have been shown to have with other cognitive abilities such as verbal intelligence (Carroll 1993). Therefore, it may be the case that spatial cognition provides a support for some other cognitive process, which in turn has the positive impact on performance in engineering education. With the potential for third variable contributions in a study, exposing a direct etiological link for the role of spatial skills in STEM success becomes difficult if not impossible. With any potential study that endeavors to investigate the etiology of this well-established relationship, a method capable of capturing data relating to the underlying cognitive processes students use when completing developmental tasks or problems is necessary.

In a more recent study, Delahunty et al. (2015) investigated the cognitive approaches STEM students utilized in conceptualizing problems. The findings of this study indicated a distinct advantage in utilizing spatial visualization processes in conceptualizing the tasks. The data showed that students who adopted spatial approaches, as opposed to other cognitive processes such as analytical reasoning, were able to gain broader access to different types of memory systems, which facilitated more adaptive problem solving behavior (Delahunty 2015). Problem solving plays a large and critical role in engineering education. It is possible that the gains in performance in engineering education in general are attributable to the impact of spatial skills on problem solving performance. However, the key strength of this study in the context of investigating the underlying causality is the novel approach of gathering EEG data. This allows an objective approach to observing evidence of participants' cognitive processing during problem solving episodes.

Conclusions

This short literature review presents a starting point to begin a focused investigation into the etiological foundations of the well-established link between spatial skills and success in engineering education. Understanding this link has numerous potential implications for teaching and learning within engineering education. If it were possible to isolate the direct causal source for the role of spatial cognition in STEM learning then it would be possible to enhance and develop precise educational approaches with engineering programs. Engineering graphics instruction, which has been minimized or eliminated entirely in recent years, could play a dominant role in curricular reform aimed at improving spatial skills across engineering education. Felder and Silverman (1988) discuss the potential mismatch between learners' preferences and teaching styles. Explicating the etiological foundations of the relationship between spatial skills and STEM success may aid in bridging this gap by informing educators of the critical role of spatial cognition in different aspects of engineering education. For example, if spatial cognition is key in the conceptualisation of engineering problems (Delahunty et al. 2015) then focused interventions of visually conceiving and representing problems could be further developed.

As discussed by Barak (2011) further exploration of the cognitive processes underlying learning within engineering education will foster the development of self directed and self regulated learners capable of solving complex and multi-faceted problems in society. A critical issue among engineering education graduates currently is the sub-standard problem solving and reasoning abilities observed in the workforce (National Academy of Engineering 2004). Therefore, it is important to consider manners in which the development of these cognitive aptitudes can be fostered within current conceptions of engineering education. Exploring the causal link between success in engineering education and spatial achievement is a necessary step in enhancing the potential of engineering graduates.

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