Exploring the role of spatial skill in electrical circuits problem solving

Thomas Delahunty, Lance C. Pérez and Presentacion Rivera-Reyes
Department of Electrical and Computer Engineering
University of Nebraska-Lincoln

Abstract

Spatial skills have a known beneficiary role in STEM students' academic success. This paper explores data relating to the role of spatial skills in electrical engineering problem solving which is a relatively under researched area. Data indicate a significant association between electrical engineering problem solving and spatial skills and a discussion around their potential causal role concludes the paper.

Introduction

The relationship between spatial skills and successful engagement in Science, Technology, Engineering and Math (STEM) education fields has been widely established and consistently reported. Wai, Lubinski, and Benbow (2009) go as far to state that spatial skill is a better predictor of achievement for STEM students than verbal or mathematical abilities that are commonly focused on in the majority of academic fields. Specific to engineering education, spatial skills have been found to be related to performance in calculus (Sorby, Casey, Veurink, & Dulaney, 2013), mechanical reasoning (Casey, Nuttall, & Pezaris, 2001), electrical concepts (Duffy, Sorby, & Bowe, 2016), and mathematical problem solving (Boonen, Wesel, Jolles, & Schoot, 2014). While it is generally accepted that spatial skills have a key role in STEM learning, their precise role in engineering education is not yet well understood (Delahunty, Sorby, Seery, & Pérez, 2016). More specifically, while some engineering fields such as mechanical engineering have a clear need for evolved spatial talent, it is not apparent whether these abilities play a role in less imagistic engineering disciplines. This paper reports on data gathered in an electrical engineering course and explores the role of spatial skills in solving electrical circuits problems.

Research Method

Students (N=34) from electrical engineering courses within the College of Engineering at the University of Nebraska-Lincoln were recruited to take part in the exploratory study. This sample included both junior (n=20) and sophomore (n=14) students. Students were recruited by email and in person and invited to take part in both an online spatial skills measurement and a voluntary problem solving activity session. The spatial skills assessment instrument was the Mental Cutting Test (MCT), a commonly utilized tool in spatial skills research.

Problem solving tasks included 9 electrical circuits problems and 5 knowledge control problems. These knowledge control problems were to ascertain the level of conceptual understanding, on the part of the students, of the principles required to solve the 9 primary tasks. This allowed the researchers to control for domain knowledge in the analysis of the data. Given the established importance of domain knowledge in problem solving performance (Novick & Bassok, 2005), it was important that this variable was controlled to gain a more accurate measure of the relationship between spatial skills and electrical engineering problem solving. These knowledge control tasks were simplified questions that ask the students to state certain fundamentals like Ohm's Law or explain the difference between series and parallel resistors. In addition, students were also assigned a series of mathematical problems (6) as an additional variable to aid in the subsequent analysis by controlling for mathematical problem solving ability.

Electrical Circuits Tasks

The 9 primary tasks were circuits problems taken from the DIRECT 1.1 electric circuits concept test (Engelhardt & Beichner, 2004). These were organized into three categories; 1) Conventional 2) Unconventional and 3) Word problems. The conventional category included three circuits tasks presented in a typical format that students will be familiar with from textbooks. The unconventional category included three tasks where the elements of the problem diagram were manipulated into an unconventional presentation. It is important to note that the intrinsic nature of the problem is not being altered only the presentation. The word problems asked students to solve three circuits tasks presented entirely with a written description. A sample problem and justification for inclusion from each category are presented in Figure 1.

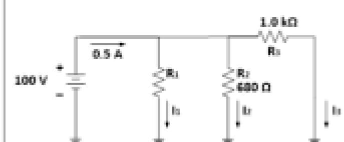
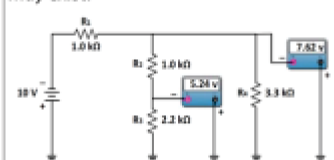
Word Problems	Conventional Problems	Unconventional Problems
Many types of decorative lights are connected in parallel. If a set of lights is connected to a 110 V source and the filament of each bulb has a hot resistance of 2.2 kΩ, what is the current through each bulb? Why is it better to have these bulbs in parallel rather than series?	*Find the values of R_1, I_1, I_2 and I_3 in the circuit shown in figure below.* 	*Check the meter readings in figure shown below and locate any fault that may exist.* 
Rationale: This style of problem format has been shown to be associated with spatial skill as students are required to construct a representation for the task (Boonen et al. 2014)	**Rationale:** These are problems that students should be most familiar with from textbooks etc.	**Rationale:** Presenting problems in an unconventional format may require students to utilize their spatial cognitive resources to a greater extent given potential unfamiliarity (Domin and Bodner 2000)

Figure 1: Sample Task from Each Task Category

Findings

Performance Overview

Performance on the MCT was varied and the mean score was 50.6% with a standard deviation of 24. Students performed well on the mathematics problem-solving tasks recording a mean score of 72.9% and standard deviation of 26.8. In the electrical circuits problems, students performed well with a mean score of 89% and standard deviation of 11.9. The categories (Word, Conventional and Unconventional) demonstrated mean performances of 93.1%, 96.1% and 79.4% respectively. To determine any significant differences in performance for these categories a Friedman test was conducted. A significant difference in performance was recorded across the task groupings (Word, Conventional and Unconventional) $\chi 2$ (2, n=34) = 19.16, p <0.005). Inspection of the median values indicate that students performed similar in the Word and Conventional categories (Md = 100) and poorest in the Unconventional (Md=66.7) category.

Relationship between Spatial Skills and EE Problems

In order to determine if any association exists between performance on the MCT and performance on the electrical circuits problems a partial correlational analysis was conducted. This statistical method was selected in order to control for potential impact caused by conceptual knowledge and mathematical problem solving ability. Therefore, two separate correlations were conducted between scores on the electrical circuits problems and the MCT while controlling for performance scores in the electrical circuits questions and math problem solving respectively. Controlling for the variable of conceptual knowledge, a large significant association was found between performance on the electrical circuits problems and the MCT (r = .521, p < .005). A moderate correlation was found when performance on the math problems was used as a controlling variable (r = .387, p < .05). This indicates that spatial skills, as measured by the MCT, was a contributing variable beyond both conceptual understanding and mathematic problem solving ability for these students. Subsequent analysis was conducted with the spatial scores and scores in each of the three task categories. This subsequent analysis did not reveal any further associations between MCT scores and performance in the word or conventional categories of tasks. The analysis did reveal an association between MCT performance and the unconventional category of tasks, *rho*=.522, n=35, p<0.01.

Discussion

The findings of the study address the dearth in the literature regarding the role of spatial skills in electrical engineering curricula. The novel contribution of this study lies in the use of electrical circuits problem solving tasks rather than simple conceptual understanding tasks alone. To the authors' knowledge, this has not been conducted in great detail within the field previously. The findings illustrate the spatial skills, as measured by the MCT, was a contributing variable to students' performance on the electrical circuits problems. This correlation remained significant when conceptual knowledge and mathematical problem solving ability were controlled. This provides empirical support for the role of spatial cognition in the process of solving electrical circuits problems.

It is still unclear as to what exact role spatial ability has in the process of solving these problems, but it is possible that their contribution lie in students' representation of the problem. The data indicate that a significant correlation exists between spatial scores and performance in the unconventional category where students may require enhanced representational competencies to construct an effective problem representation. This is supported in previous work by Pribyl and Bodner (1987) and Bodner and Domin (2000) who found increased involvement of spatial processes when problems are unfamiliar to students. This evidence highlights a potential contribution of spatial processing to the problem representation phase.

A limitation of the current paper is the reliance on correlational data only. This is the common approach to investigating the relationship between spatial skills and academic success and is a useful exploratory approach. However, there is a need to consider deeper investigations into the precise role of spatial cognition in engineering problem solving (Delahunty et al., 2016). This paper controlled for additional variables which adds strength to the approach but future work will incorporate the use of EEG technology (Delahunty, Seery, & Lynch, 2013) and representational analysis as research tools.

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