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Predicting creative problem solving in engineering design

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ABSTRACT

Developing students' creative problem solving (CPS) is widely considered to be an important goal in engineering design education. However, the cognitive processes required for CPS are not currently well understood, limiting educators' capacity to support this ability in students. This study used three cognitive abilities: divergent thinking, working memory, and relational reasoning to predict CPS in engineering design graduate students both before and after they learned to use the TRIZ ideation method. TRIZ, a Russian acronym meaning Theory of Inventive Problem Solving, is a method for improving the originality of the designs that engineers generate. In this study, relational reasoning is conceptualized as a construct encompassing analogical, anomalous, antinomous, and antithetical reasoning. In this study, master's level engineering design students were given a creative design task before and after they were instructed on the TRIZ method. Then, their performance before and after instruction was compared. Using paired sample *t*-tests, it was found that participants produced significantly fewer design ideas after TRIZ instruction than they had before. But, TRIZ informed designs were significantly more original than those produced before. In a sequence of linear regression models, relational reasoning was found to be the strongest predictor of the originality of designs both before and after TRIZ instruction. Antinomous reasoning in particular was implicated in the production of original designs using TRIZ.

1. Introduction

The design engineers of today are confronted with a number of important and extraordinary challenges. For example, engineers are pushed to create new products that will at once be lucrative and helpful to humankind. However, fundamental constraints and contradictions, such as the need to be environmentally conscious while being cost effective, minimizing energy requirements while still providing adequate operating power, increasing device accessibility to all users while simplifying manufacturing activities, and promoting sustainability complicate this endeavor. In recognition of these important endeavors, The National Academy of Engineering has posed "grand challenges" to the engineering community designed to motivate innovation in today's complex world (NAE, 2014). For example, engineers are tasked with designing new solar energy technology to surpass current conversion efficiencies of roughly 30%, while simultaneously reducing the cost of solar energy production (NAE, 2014).

As the engineering design community continues its focus on challenges such as these, a critical question has been posed: how can engineering design students be adequately prepared to engage effectively with today's engineering challenges? In

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response to this question, numerous scholarly (e.g., Passig & Cohen, 2014; Vargas Hernandez, Schmidt, & Okudan, 2013) and popular publications (e.g., Boss, 2012; Wagner, 2012), governmental policy reports (National Science and Technology Council, 2013), and even presidential addresses (Obama, 2011) have given this general response: cultivate creative problem solving. This general call for creative problem solving in engineering design education is driven by the observation that few of today's major engineering challenges (e.g., producing technologies to combat climate change) can be solved through the simple application of existing processes or equipment. Therefore, novel technology, materials, and systems must be engineered. Crucially, without the development of creative problem solving, the next generation of engineers may be unprepared to create novel designs. In this way, creative problem solving is deeply important for engineering designers.

Despite the widely acknowledged importance of creative problem solving in engineering design, the actual effectiveness of engineering design education in fostering the creative potential of students is relatively understudied (Charyton, 2014). Today, many design methods exist with the explicit purpose of improving the creativity of designs (e.g., Theory of Inventive Problem solving [TRIZ]; Altshuller, 1996; WordTree; Linsey et al., 2012), but their effectiveness has rarely been systematically examined. Further, the cognitive capacities that predict students' ability to benefit from such design methods, or to think creatively about engineering design problems in general, is severely underexamined. Here, we examine the effectiveness of one widely used engineering design method, TRIZ (Altshuller, 1996), and investigate the predictive relation of three cognitive abilities (i.e., divergent thinking, working memory, and relational reasoning) to two components of creative problem solving (i.e., fluency and originality) in the performance of graduate students enrolled in an engineering design course.

1.1. Components of creative problem solving

Creative problem solving is often measured in terms of a number of interrelated processes or components (Silvia, Martin, & Nusbaum, 2009). Two of the most commonly measured components are *fluency*, which refers to the quantity of ideas that a participant is able to generate, and *originality*, which refers to the comparative novelty of each of those generated ideas (Hocevar, 1979; Hokanson, 2007; Runco & Mraz, 1992; Silvia, 2008). Fluency can be relatively easily and objectively assessed in performance by simply counting the number of distinct ideas individuals generate (Benedek, Fink, & Neubauer, 2006; Torrance, 1972).

Originality, on the other hand, has historically been operationalized in variety ways, including by means of multiple raters (e.g., Sternberg, 2006), semantic networks (Dumas & Dunbar, 2014), and relative originality algorithms, which measure how original a given idea is within a given sample (Silvia, 2008). Importantly, such an operationalization of originality stems from a theoretical orientation rooted in the history of psychometric investigations of creativity (e.g., Hocevar, 1979; Torrance, 1972), in which originality is theorized to represent the unlikeliness that a given idea will be put forward by a given participant drawn from a particular sample. Therefore, based on this theoretical standpoint, those ideas that are common in a dataset are considered less original than those ideas that are uncommon. When examining creative problem solving within a particular domain, such as engineering design, relative originality algorithms may be the most valid, because they allow for a high degree of objectivity in scoring (Shah, Smith, & Vargas-Hernandez, 2003; Vargas Hernandez et al., 2013), and approximate the way originality is conceptualized in the professional practice of engineering, where ideas are original only if they are rarely generated in a given professional context (Passig & Cohen, 2014).

Moreover, relative originality algorithms are particularly suited to scoring the originality of creative problem solutions within the domain of engineering design, because designs can be coded based on the physical and working principles utilized (Shah et al., 2003; Vargas Hernandez et al., 2013). Here, a physical principle refers to the general aspect of a design that allows for a problem to be solved. For example, mechanical and chemical physical principles, among others, may be utilized. Further, a working principle refers to the particular way in which a psychical principle is instantiated in a given design. For example, mechanical solutions for preventing snow accumulation on a surface may be instantiated by a number of particular working principles including; covers, vibration, or wipers. (See Table 1 for a full list of physical and working principles utilized in this study.) This method for modeling designs is consistent with the functional representation system popularized by Pahl, Beitz, Feldhusen, and Grote (2007) and serving as a foundation for a function-based modeling system in engineering design (Hirtz, Stone, McAdams, Szykman, & Wood, 2002).

While previous research has investigated the efficacy of the TRIZ method in terms of the creative performance of designers, that creative performance was frequently assessed in terms of only one component of creative problem solving, such as fluency or originality (e.g., Nordstrom & Korpelainen, 2011). Indeed, studies of changes in fluency and originality in response to TRIZ instruction have been limited (Dumas & Schmidt, 2015). In this study, we examined changes in the performance of engineering design students associated with the TRIZ method in terms of both of these components of creative problem solving.

1.2. TRIZ method

TRIZ is an acronym for the Russian *Teoriya Resheniya Izobretatelskikh Zadatch*, meaning *theory of inventive problem solving*. The TRIZ method is a systematic process that has been used for decades to support design engineers' creative problem solving, first formulated by Soviet naval engineer Genrich Altshuller. In the TRIZ method, Altshuller (1996) sought to objectively describe the creative process, and construct a mechanism for the systematic support of human designing of invention. Therefore, Altshuller posited the TRIZ method, which includes application of inventive principles in appropriate design