SYSTEMS THINKING FACTORS AS PREDICTORS OF SUCCESS IN ENGINEERING DESIGN

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1. The Cognitive Profile of Successful Designers

Design is a task performed by a designer, and thus the quality of the design is directly influenced by the knowledge, experience, and cognitive traits that the designer possesses. The cognition underlying successful design has proven difficult to capture, even though its illumination holds great potential for research in engineering design. Systems thinking as a concept has been studied across several fields, and as a result, has been given many definitions. Though a consensus definition has yet to be reached, many have in common two features: it is a cognitive style that deals with systems, and is carried out through a set of cognitive competencies that allow one to understand, solve problems within, and design systems. Moti Frank's Cognitive Competency Model (2012) offers sixteen competencies that are believed to make up systems thinking. Influential and an imperative base for future research, this model was meant to be a theoretical grounding; thus, how these competencies may be measured was not included. To address this concern, Greene and Papalambros (2016) mapped Frank's cognitive competencies to constructs from psychology, offering a basis for future research on cognition within systems thinking. They leave open the possibilities of which psychological tests to leverage. Additionally, research on the relative importance that the different cognitive competencies hold within engineering design is underexplored. Therefore, there is a lack of knowledge of how quantitatively various system thinking factors influence design success.

2. Research Objectives

The objectives of the present study are to address two gaps found in the previous research on systems thinking in engineering design. First, to examine the relationships between a design task representing engineering systems thinking ability and a battery of psychological tests representing Greene and Papalambros' (2016) mappings of Frank's cognitive competencies (2012). Second, to observe which of these competencies are most important when predicting performance on systems design tasks.

3. Engineering Design Task

To quantify performance within engineering design, a design competition was conducted and completed by thirty-four participants. Administered through the Energy3D, a computer-aided design research program (Rahman et al. 2019), participants competed against each other to create a solution to a given design problem. Given the context that the host university desired a proposal for a cost-effective and economically self-sustaining solar energy system for a local dormitory and adjacent parking lot, participants were given the objective to design a large-scale system of solar panels to generate at least 1,000,000 annual kilowatts with a budget of $1,900,000, and a system payback period of under 10 years. Alongside these goals, design constraints were included to emulate the many restrictions present when designing engineering systems in the professional world. More information on the design challenge, and a list of constraints can be found on

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the lab's website: sidilab.net. The nature of participants' design was quantified in three ways: a performance metric (a ratio of annual energy output to the cost of the system), an objective metric (the payback period for the participant's design), and the number of design iterations they employed.

4. Hypotheses

Due to the number of design metrics and hypotheses, this section begins with a brief introduction of each of the psychological tests used and ends with the relationships that we expect to uncover.

The Keep Track test (modified from Miyake et al. 2000) was used to capture participant's working memory, a process used for storage and manipulation of information (Baddeley 1992). As systems are aggregates of variables, success in this realm should be influenced by this construct. Additionally, the more data one can consciously consider at once should decrease how frequently they must test their iterations.

The International Cognitive Ability Resource (ICAR; Condon and Revelle 2014) is a broad measure and consists of four item types, each of which analogous to several of the constructs listed by Greene and Papalambros that reference reasoning ability.

Creativity research is demarcated between two constructs: divergent and convergent thinking. Divergent thinking encompasses idea generation and is studied through four sub-constructs: fluency, originality, flexibility, and elaboration. Convergent thinking is characterized by choosing the correct solution to a problem. To measure the former, we employ the Abbreviated Torrance Test for Adults (ATTA; Goff and Torrance 2002); the latter, the Compound Remote Associates test (Bowden and Jung-Beeman 2003). The two are widely used measures within the field, and both Frank along with Greene and Papalambros cite creativity. Included was a measure of openness to experience, a personality trait shown to positively correlate with several measures of creativity (McCrea and Costa 1999; McCrae 1987).

The Four-Factor Imagination Scale (FFIS; Zabelina and Condon 2019) measures it's the four sub-constructs: fluency, complexity, emotional valence, and directedness. Prospection and hypothetical thinking are both mentioned by Greene and Papalambros, similar to imagination in problem-solving.

As each of the psychological tests was employed to measure the cognitive competencies that make up and contribute to the success of systems thinking, our hypotheses for each construct are similar. For our design performance metric, we expect the following tests to show a positive correlation: the Keep Track test, ICAR, the ATTA and each of the sub-constructs, CRA, the fluency, directedness and complexity of imagination, and openness to experience. For the objective metric, we expect negative correlations between the identical list. Lastly, for the number of design iterations that participants employed, we hypothesize there will be a negative relationship between the Keep Track test and directedness of imagination, and positive correlations with fluency within both the ATTA and the FFIS.

5. Preliminary Results

Before the results of the statistical tests used to address the previous hypotheses, several points must be addressed. First, it is the researcher's intention to collect additional data identical to what has already been gathered; as a result, to avoid bias a predictive model will not be built until the remaining data is collected. Second, due to the large number of hypotheses, they will not each be considered individually in the current abstract; the poster will address all hypotheses. The following are the correlations between the psychological measures and design metrics that reached, or show a trend towards, significance. Against our hypothesis, the performance metric showed a negative correlation with the directedness of imagination ($r = -.347$, $p = .059$). Towards our hypotheses for the objective metric, the Keep Track test and number of correct answers on the CRA both showed negative correlations (respectively, $r = -.318$, $p = .105$; $r = -.382$, $p = .078$). As hypothesized, the number of design iterations was negatively correlated with the Keep Track test, and directedness of imagination (respectively, $r = -.337.$, $p = .079$; $r = -.399$, $p = .028$). Note: r denotes correlation analysis and p denotes p-value. The level of significance adopted is .05.

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