The role of precedents in increasing creativity during iterative design of electronic embedded systems

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This paper presents a study on the role of precedents in illuminating creative ideas during iterative design for solving open-ended problems in electronic embedded systems. Through an experimental study grounded in cognitive psychology, this work examined the influence of precedents on the novelty, variety, quality, and utility of design solutions devised through an iterative design process involving groups of participants. Another tested hypothesis was whether incremental changes of requirements improve novelty. Results show that precedents did not increase solution novelty and quality, but improved utility. Precedents reduced design feature variety as solutions converged toward a few dominant designs. Incremental modification of requirements did not increase novelty.

Keywords: creativity, design precedents, system design, design cognition, iterative design

Design problems in electronic embedded systems are often open-ended as they address new core applications and functionalities in emergent yet important domains, like intelligent infrastructure, robotics, healthcare, automotive industry, and many more. Open-ended design problems are incompletely specified, or represent needs based on organizational or personal perspectives, judgments, and predictions (Coyne, 2005; Darlington & Culley, 2004). Other kinds of design problems include fully-specified, well-defined problems and fully-specified, infeasible problems (Goldschmidt, 1997; Schon, 1983; Shelly & Bryan, 1964). Fully-specified, well-defined problems are described as complete sets of requirements solved through optimization or transformation methods. Tackling fully-specified, infeasible design problems involves finding the contradicting requirements and then solving these through specific resolution rules (Altshuller, 1988; Bledow, Frese, Anderson, Erez, & Farr, 2009; Dubois, Eltzer, & De Guio, 2009).

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Creativity is important in solving open-ended design problems because new goals and functions, novel design solutions, and original resolution rules must be found. There are many definitions of creativity (Bink & Marsh, 2000).

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Creativity is often characterized by referring to the novelty (e.g., solutions have less frequent features) and utility (i.e. solutions satisfy precise needs) of the solutions (Amabile, 1983; Mobley, Doares, & Mumford, 1992; Sternberg, 1999; Thagard & Stewart, 2011). Creativity in physics is described by inventiveness and orderliness, and creativity in art is represented by imagination and originality (Sternberg, 1985). In engineering, design creativity is characterized by the level of meeting goals (Shah, Vargas-Hernandez, & Smith, 2003). Guilford (1956) suggests that the cognition factors involved in creativity are fundaments (e.g., words), classes (categories), relations, patterns, problems, and implications. Innovation originates through a process that includes both convergent and divergent thinking. Convergent thinking refers to naming objects, classifying objects into categories, finding correlations, identifying patterns, finding changes, and providing unique conclusions. Divergent thinking involves finding different words with the same properties, producing alternative relations with the same meaning, and changing a structure's meaning for a new purpose. A broad set of theories and models on creativity are discussed in the research literature in cognitive psychology (Amabile, 1983; Guilford, 1950; Kohn, Paulus, & Choi, 2011; Mobley et al., 1992; Simonton, 2010; Sternberg, 1999; Vosniadou & Ortony, 1989; Ward, Patterson, & Sifonis, 2004).

The relation between creativity theories and models in cognitive psychology and innovation in engineering is subtle. Many creativity tests in cognitive psychology neglect the comprehensive nature of engineering design and ignore domain-specific information. For example, tests on divergent thinking are weak when used to measure and predict creativity in real-world situations (Mansfield, Busse, & Krepelka, 1978; Zheng, Proctor, & Salvendy, 2011). Other creativity models focus on concrete innovation situations while considering more specific engineering problem details. Bledow et al. (2009) define innovation as contradiction solving. Altshuller (1988), the creator of TRIZ method, proposes a set of rules to resolve a broad variety of contradictions. Dubois et al. (2009) extend TRIZ into Generalized Contradiction model, in which combinations of contradictions are identified for given engineering problems. Other approaches to design innovation suggest problem-solution co-evolution (Dorst & Cross, 2001; Shang, Huang, & Zhang, 2009). Poon and Maher (1997) propose co-evolving problem descriptions and solutions by combining genes with modified behavior from interacting populations of problems and solutions. Kryssanov, Tamaki, and Kitamura (2001) describe a model for the dynamics and non-determinism of design.

In spite of the breadth of existing work on creativity and design innovation, there are still few design creativity studies that capture the specifics of electronic embedded system design problems while being grounded in models devised in cognitive psychology. Electronic embedded systems have several characteristics that distinguish them from other general-purpose or engineering problems: