Creativity under Constraints: The Effect of Design Problem and Design Space on Creativity and Learning among Engineering Students

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Abstract: An understanding of what facilitates creativity in the design process is essential to the configuration and construction of engineering design activities for educational environments. In my dissertation research, I propose to investigate the relationship between creativity, design education and student learning. To examine creative practices among students in a design based learning environment, I am examining engineering design processes in the context of a sustainable energy design project. In particular, I am looking at the role of design constraints on creative processes. I am comparing constraints that arise from the design space given to students -- one group of teams creates design solutions for a specific site utilizing sustainable energy and the second group creates design solutions for a broader context – and constraints within a given design problem space. In this setting, I specifically investigate the role of constraints in the design process and their effects on creativity.

Goals of Dissertation Research

Gero (2000) views design as a creative activity, a source for innovation and basis for social reform. Previous research examines the role of creativity and innovation in design through various artifacts, for example, considering the role of brainstorming and design alternatives on creative solutions. While large numbers of alternative solutions often correlate with creativity, it is unclear exactly how the design constraints contribute to the decision-making process and final design choice. The National Academy of Engineering (1998) defines engineering as "design under constraint", the creation and design of "what can be" constrained by nature, cost, safety, reliability, environmental impact, manufacturability, maintainability, and many others. Innovativeness is defined as one key characteristic of the Engineer of 2020 (NAE, 2005; NAE 2004) and several agencies (NAS, 2003) call for the production of an innovative and creative workforce. In engineering education, engineering design activities provide students authentic experiences where resource constraints (e.g. materials, time, space, etc.) design guidelines ultimately force students to be inventive and creative. Creativity in the context of engineering design activities relates to cognitive activity and problem solving (Ward, Smith, & Finke, 1999). However, I am interested in what types of constraints contribute to the decision making process and ultimately identifying the links between constraints and learning and cognition. With this work I intend to contribute to the field of engineering education by identifying and integrating the role of constraints into design education.

Prior Background Related to Dissertation Research

Prior to starting my doctoral program I worked on another project related to creativity and that has shaped the direction of my dissertation research. In that project I studied the role of requirements in an engineering capstone design course. The project was an observational study of 50 student design teams in a product realization class. Undergraduate and graduate electrical, mechanical, bio, industrial, and chemical engineering and business students worked together on interdisciplinary teams. The industry-sponsored projects encompassed a variety of domains and included projects to design solutions for communicating through nuclear plant concrete containment walls, a post-surgery wearable device for monitoring eye pressure, and floor tiles made from recycled materials. In order to study design methodology and its effect on design outcome I specifically focused on how design teams generated, identified, and met their project requirements. In developing a methodology for studying success factors in heterogeneous product realization projects, I found that teams who were able to identify relative importance ratings based on expert importance ratings was a determinant of project success. My work on this project motivated me to further investigate the intricate and complex components of the design process.

Theoretical and Methodological Frameworks

Design Based Learning

The challenge in the design of instruction lies in finding an ideal combination of learning opportunities that effectively prepare students for their domain outside of the academic setting. While Feldman (1999) states that professional preparation varies from field to field, design-based learning is one context employed in engineering that enables us to study how students engage in the design process by integrating creative approaches. Design-based learning (DBL) environments encourage students to engage in their innate curiosities in a fun, interactive environment that develops higher-level reasoning skills (Art Center College of

Design, 2007). These particular environments are similar to the more traditional problem-based learning environments (PBL), however, DBL environments extend the elements engaging students in a design and planning process of an engineer (Mehalik & Schuun, 2006). Moreover, DBL situates students in a more active learning environment, which is argued to enable students to relate problems to science concepts (Thomas, 2000). Consequently, DBL environments encourage students to think critically at the highest level; to predict, *be innovative*, extrapolate, adapt and transform information, thus gaining a deeper understanding of subject matter (Nelson, 2008). The critical implications of a DBL environment highlight the importance in understanding the relationship between creativity and constraints and their role in education.

<u>*Creativity*</u>

Creativity and ***Learning***

Creativity and learning have always had a longstanding and important relationship. While creativity can be an innate characteristic, research suggests that it is also enhanced through various means in the classroom (Park & Seung, 2008). Thus, it is imperative that educators incorporate and implement activities that are specifically designed to facilitate and encourage students' creativity in the classroom.

Within general learning contexts, creativity is important for economic, social, and individual growth and is a key element in building scientific knowledge (Csikzentmihalyi, 1996; Popper, 1992). More specific contexts, i.e. engineering education, cite creativity as a primary goal (NACCCE Report; Robinson, 2001). One strategy to increase students' overall creativity is to engage students in creative problem-solving activities (Park & Seung, 2008), for example, design activities and projects that involve open-ended problems or tasks encourage students to use innovative methods and strategies. By providing problem-solving activities and design activities in an educational setting, students have the opportunity to explore a solution space working under various constraints. What needs further investigation are the types of constraints that affect the decision making process and if other external factors facilitate creativity, e.g. technology.

Creativity and ***Technology***

Creativity has always been closely linked with advances in technology and innovation; therefore it follows logically those technology-based learning environments in education to help to develop students' creativity and innovation skills. Unfortunately, creativity does not happen by chance, but rather it must be fostered and nourished by environmental conditions (Glover, 1980; Peterson, 2002). Glover (1980) cites originality and purpose as two essential conditions that creativity must satisfy. Extremely innovative technologies serving no practical purpose have little or no value in a real-world context. In contrast, a product with significant practicality and limited originality cannot necessarily be considered creative (Peterson, 2002). Several studies (Selker, 2005; Berry & Hamilton, 2006) suggest that technology can facilitate creativity, more specifically, Berry & Hamilton (2006) found that Tablet PCs allow for the manipulation of visual ideas.

With the understanding of specific learning technologies', i.e. Tablet PCs, affect on visual idea and representation, it is essential to study exactly how these learning technologies shape the creative processes in design-based environments. Given the significant research underlining the importance of design-activities and the influence of learning technology on creativity, it is advantageous to study the complex relationship between creativity and constraint in design-based learning environments.

Research Questions

My primary research questions are:

1. What role do constraints play in facilitating creativity in design-based environments?
2. What types of constraints are significant in the design process and how do constraints influence the search of the solution space and decision making process in design activities?
3. In relation to design constraints, I plan to examine the role of technology and digital representation in creativity. More specifically, how can learning technologies, situated specifically in design-based environments, facilitate creativity and innovation in engineering classrooms?

Methodology

<u>Setting and Data Collection</u>

The context for this study was a foundational engineering course for freshman engineering students not enrolled in a specific engineering discipline. The engineering students developed "innovational solutions" to highlight the usefulness and effectiveness of renewable energy for a farm in New Hampshire. Throughout the nine-week design project, students developed innovative solutions to address the broad concerns of clients looking for alternatives to the current non-renewable energy practices. Students had direct communication with their clients, who provided them with information regarding the design site. The clients were looking for alternatives to the current non-renewable energy practices. In order to facilitate the design process the students completed pre-assigned milestones, which included sketching, brainstorming and prototyping. Student employed their Tablet PCs to complete the milestones but had the option of using their tablets to for the construction of the design artifacts. One definitive constraint imposed on every group was a budget constraint for constructing the final design. The overall goal for the design solution was to assist the clients in their energy needs but also serve as a model for other innovations that can help people who live in rural areas become self-reliant and less dependable on non-renewable energy sources. The study was done in conjunction with other sections of the over-arching course who not working under the same design context. The objectives, design activities, and assessment methods were essentially the same for sections not working under a specified design context and sections working under the New Hampshire farm context. For all engineering design teams, one or more key components of a renewable energy source were required for the design; the design was also encouraged to educate, entertain, and generate further inquiry into creative renewal energy solutions. The measures of creativity for the finals design include peer assessment, instructor assessment, and assessment by the clients.

Table 1: Data Collection Methods

Method	Description
Observations	Audio and video recording and field note documentation of in-class design activities, individual team design project meetings, team/ instructor design project meetings, and design presentations
Focus Group Interviews	Design project follow-up interviews with teams who agreed to meet outside of class for observations recorded with audio. Interview questions include team member perspective on the role of previous experience and project requirements in their design process.
Design Artifacts	Preliminary design site research report, Brainstorming inventories, team evaluations, team logs, sketches, design prototype, and Final design report and presentation (See Table 2 for detailed descriptions)
Surveys	Pre- and post- design project surveys regarding student experience in design, technology, creativity, sustainability, and teamwork.

Table 2: Design Artifacts

Deliverable	Collected from Individual or Team	Description	Form of Assessment
Background Survey	Individual	Electronic survey to elicit previous design and team experience details	Instructor
Research Report	Team	Research document on the current energy consumption and geographical details of design project location	Instructor
Brainstorming Inventory	Team	List of potential design ideas for the final design development; also includes the design description and primary author of the idea	Instructor
Team Member Evaluations	Individual	Evaluation form and perspective from each team member on team dynamics and project progress	Instructor, Peer
Sketch	Individual	Electronic or paper-based hand sketch communicating each member's idea of the design solution	Instructor
Prototype	Team	Prototype or preliminary representation of the final design solution; presented in a gallery forum to receive peer feedback	Instructor, Peer
Team Log	Team	Comprehensive summary of all team meetings throughout the duration of the project	Instructor
Team Demo and Presentation	Team	Demonstration of the final product or complete working model to the class, instructor, and client	Instructor, Peer, Client
Final Report	Team	Detailed report on the entire design process including the team's engineering analysis of the design solution	Instructor, Peer, Client
Debriefing Survey	Individual	Survey to elicit student perspective on the contribution of previous experience in design, technology, teamwork, and sustainability to the overall success of the project	Instructor

Current Status

I have collected data for two iterations of the student design project and begun preliminary data coding and analysis. I am currently coding the brainstorming sessions and brainstorming inventories guided by March's (1990) theoretical framework for exploration and exploitation. The variation in design solutions offered by the teams and survey of their prior experiences suggests a strong link between exploitation, so I am looking for specific instances where these ideas contributed to the decision-making process.

Preliminary Results

Upon analyzing the feedback and assessment by the clients, there was a direct correlation found between positive feedback and previous design experience. However experience in design, technology, teamwork, or sustainability was not found to be statistically significant predictors of a student's overall project assessment grade. From the initial analysis of the brainstorming inventory over half of the teams chose an idea conceived in the brainstorming inventory/ brainstorming session to develop for a final design while the others combined two or more ideas for their final design. Searching the solution space through the brainstorming session and brainstorming inventory appears to be a useful method for exploration of ideas. Although previous experiences in design, technology, teamwork, or sustainability were not significant predictors of overall project assessment, the lack of significant findings is more likely an effect of the design assessment measure in this project.

Expected Benefits of the Consortium

By participating in this graduate symposium, I intend to receive feedback on my current and future data analysis methods. I am starting analysis of video data and will like to learn from others about managing and analyzing video data. I would also find it invaluable to my research and the research within my field to receive feedback from a panel of participants from various domains in this unique forum. Feedback on the framework I am developing for identify and categorizing types of constraints based on a composite from various fields that have studied creativity under constraint would be extremely useful in providing a perspective from fields outside of engineering. I also would like to encourage discussion and ideas regarding an integration of engineering and art design from my research in creativity under constraints.

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