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The Effects of Design Thinking Methods on Pre-service PK-12 Engineering and STEM Teacher Capabilities, Confidence, and Motivation in Creativity (Work in Progress)

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Rationale and Background

Creativity is an essential habit of mind for engineers and inherent in the engineering design process.[1] Creative thinking in design is a focus of engineering education and K-12 engineering and technology education.[2-4] As future teachers will be responsible for fostering creativity in their students, it is essential that preservice teacher education programs of engineering and STEM education provide students with the opportunity to gain capability, confidence and motivation in creativity.

The Creative Design (TST:161) course at The College of New Jersey is housed out of the Department of Integrative STEM Education in the School of Engineering. The course is taken by all majors across the campus as it fulfills a fine arts liberal learning requirement. However, the highest enrollment comes from the engineering and integrative STEM majors, which is a requirement of their degree programs. The course has been in existence since the early 1960s when it was part of the Industrial Arts curriculum and focused on design from an artist's perspective. In 1969, the course underwent a reorganization, so it would bridge the chasm between the artist and the designer prepare students to better understand a "human designed world".[5]

Over the years, the objectives of the course have centered around understanding the creative process practiced by artists, designers and engineers. There is a strong emphasis on design thinking, communicating through sketching and developing prototypes to advance an idea. The design process is used as a decision-making tool that guides design from conception through manufacturing. The course also covers how the elements and principles of design are incorporated in modern products to elicit an emotional response. Impacts of design on the individual, society and the environment are explored through problem based learning. Students experience shaping a material (i.e. wood, ceramic, foam core) into a physical prototype, which for many it's the first time they have used a hand tool.

The course objectives of Creative Design provide many benefits to the students. The skills in the class help students develop spatial reasoning as well as deal with team dynamics. There is a differentiation between imagination and intelligence which expresses itself through the design process. Many of the concepts and skills stay with the students as they surface again in the senior design project. Local industries also comment on the breadth of knowledge observed in the engineering graduates. Currently, the course has 18 sections divided over the Spring and Fall semesters. The course is taught by 4 core faculty members and the remaining sections by adjuncts who have degrees in technology education or engineering. The diverse backgrounds and experiences allow each professor to vary the content and projects. It is suspected the variation can also influence the outcomes of the course, especially how they embrace creativity.

Preliminary Research

Students often come in to the class with pre-conceived notions of what it means to be creative. This can be an obstacle for many students because they might believe they are not creative since they do not self-identify as naturally artistic. In 2014, a pilot sample group of students were asked a series of open-ended questions about creativity, including: 1) "what does creativity mean?" and 2) "what are some characteristics creative people display?"

The first question received 72 unique responses and the keywords were sorted by frequency. The Wordle in Figure 1a shows the frequency of the most common words by their size. It is interesting to note most students defined creativity as an ability, which implies an aptitude some may believe they can improve while others may not. There was also an emphasis on original and unique ideas, which was expected by the nature of the question. The responses were then divided into 6 categories: 1) Thinking Differently (23.61%), 2) Developing an original idea or design (20.83%), 3) Expression through artistic means (15.28%), 4) Using your imagination (12.50%), 5) Thinking outside the box (11.11%), and 6) Other (16.67%). The overused metaphor "Thinking outside the box" was placed in its own category because the interpretation can be lost in its usage.

The second question received 114 unique responses and those were categorized into 12 characteristics: 1) Artistic (21.05%), 2) Innovative (13.16%), 3) Intelligent (7.89%), 4) Imaginative (7.02%), 5) Focuses/Perseveres (6.14%), 6) Thinking outside the box (6.14%), 7) Individualistic (4.39%), 8) Extrovert (4.39%), 9) Risk Taker (4.39%), 10) Problem Solver (3.51%), 11) Visualizes (3.51), and 12) Other (18.42%). The "Other" category grouped together other common responses that individually gave less than 3% of the total responses, such as adaptable, organized or resourceful, just to name a few. It was interesting to note that 21% of the responses directly attributed creativity to a person who is artistic (Figure 1b). If this is compared to the first question, it suggests that students realize art elements and principles can be an important aspect of divergent thinking. The responses also show that students see a creative person as someone who is confident and sees problems from a different perspective.

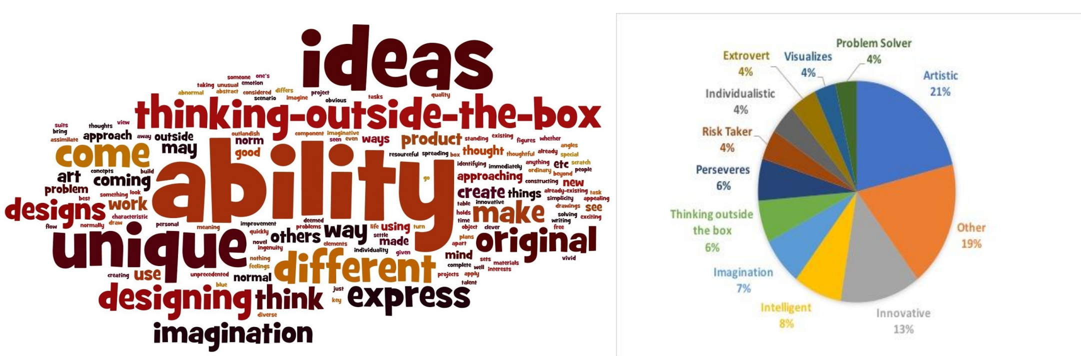


Figure 1: a) Frequency of words in responses to the question "What does creativity mean to you?" (left) b) Summary of responses to the question "What are some characteristics creative people display?" (right).

Proposed Research Design

In Fall 2016, faculty members began envisioning a more cohesive course with accompanied research design to advance creative capacity. To build a rigorous research design, it was apparent that measurement and instruction coherence was needed across multiple sections. The purpose of this paper is to present for feedback (Work in Progress) the measurement design.

Measurement

Historically, instructors of Creative Design have used individually developed measurement tools to determine progress toward course goals. Common assessment tools have been proposed to create a baseline for future research. The team of faculty members discussed appropriate evaluation instruments that would continue to allow for instructor variability and creativity but also measure the important overarching goals that are the focus of all Creative Design sections. Areas of common measurement included; (1) Creative Self-Efficacy and Creative Role-Identity, (2) Ideation Capacity and (3) Creativity in Engineering Design (Artifacts).

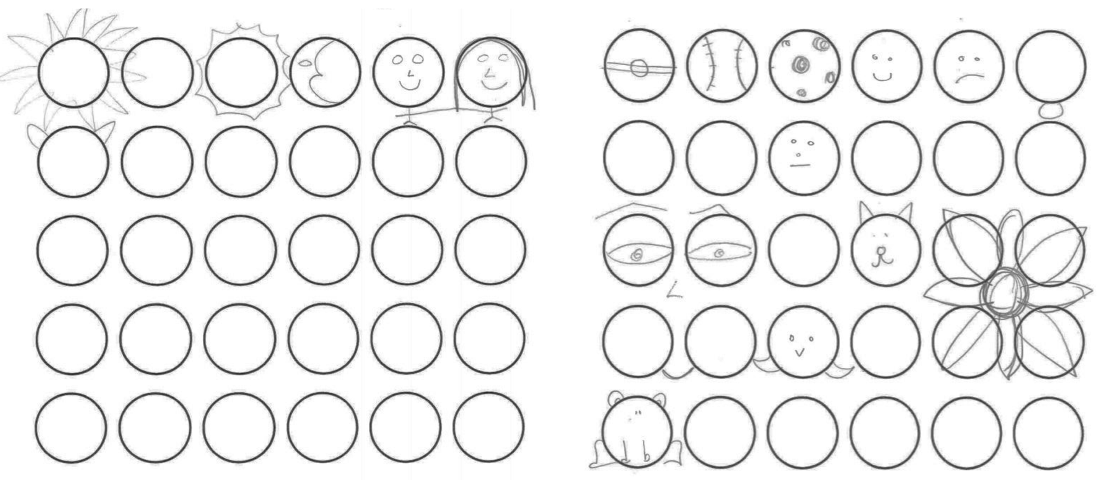
Creative self-efficacy is one's belief that they are able to design creative products[6]. Research completed by Tierney and Farmer reported that creative self-efficacy is a predictor of creative design performance. The Creative Self-Efficacy and Creative Role-Identity Scale was identified as an appropriate instrument to measure student growth through a pretest/posttest research design.[7] Surveys completed in Fall 2016 and Spring 2017 indicated that students from education school majors (n=33) have the lowest reported average score (6.34) on the scale when compared to their peers from other majors at the beginning of the Creative Design course (Table 1).

Table 1: Creative Self-Efficacy and Creative Role-Identity Scale Results (Fall 2016, Spring 2017)

School		Average (n)
Arts and Communication		6.59 (6)
Business		6.80 (17)
Education		6.34 (33)
Engineering		6.61 (43)
Humanities and Social Sciences		6.47 (15)
Nursing, Health and Exercises Science		7.07 (4)
Science		6.65 (13)
	Total	6.57 (131)

Further analysis was performed at survey item level. When comparing "Future K-12 Teachers" (many from schools other than the School of Education; e.g. Engineering, Art, Science, Physical Ed.) to "STEM" majors on survey item 3, Future K-12 Teachers (M = 6.53, SD = 1.75) indicated that they have less confidence in their ability to solve complicated problems when compared to their STEM peers (M = 7.25, SD = 1.41). While other survey items also reported differences, only the differences recorded on item 3 were found to be significant, $t(95) = 2.21$, $p < .029$.

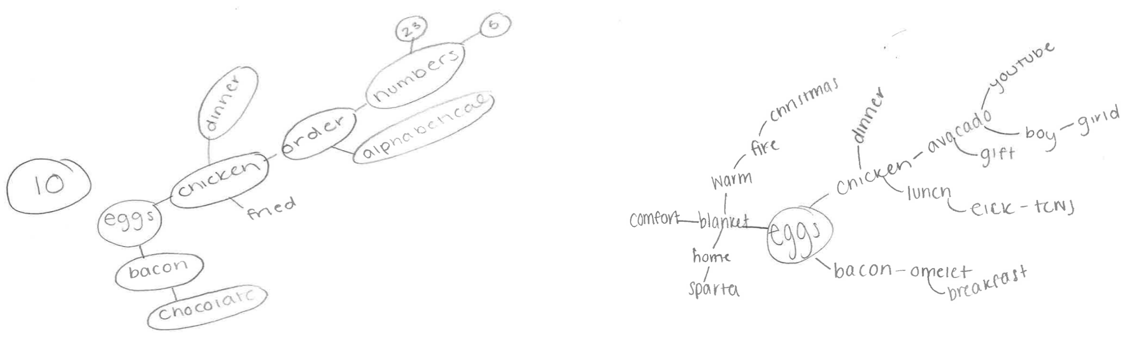
Runco, Illies, Eisenman argued creative ideas can be both original and appropriate.[8] One ideation instrument useful to measure originality is the 30 Circle Challenge in which students are asked to turn as many circles as possible into real objects. Another instrument is the mind mapping tool which can measure appropriateness by creating word associations on a focused topic. During pilot testing in Fall 2016, students completed the 30 Circle Challenge and Mind Mapping tasks at the beginning and end of Creative Design sections. An example pretest and posttest 30 Circle Challenge shows how one student was able to complete many more circles at the end of the course and demonstrated divergent thinking by their combination of multiple circles into one idea (Figure 2).



Pretest Posttest

Figure 2: A representative example a student's pretest and posttest of the 30 Circle Challenge.

An example pretest and posttest Mind Mapping tasks indicates that the student was able to generate numerous ideas that were still relevant to the topic. As discussed by Daly, Mosyjowski, and Seifert, convergent thinking such as "digging deeper" is often absent from engineering curriculum materials.[2] It is evident in the examples that the student improved in her ability to generate multiple subsidiary ideas (Figure 3).



Pretest Posttest

Figure 3: A representative example a student's pretest and posttest of the Mind Mapping Task.

Researchers have focused on artifacts of design (e.g. documentation, models, final products) to determine creative abilities.[9,10] Denson et al. employed the Consensual Assessment Technique (CAT) to measure creativity in engineering design. Denson et al. reported high interrater reliability (reported Cronbach *a* between .71-.89) utilizing a group of diverse raters (including high school teachers). The interrater reliability is especially attractive as Creative Design has a high number of diverse instructors (including high school teachers as adjunct instructors). Denson et al. measured creativity in engineering design through 3 subdimensions of creativity: Novel Idea, Novel Use of Materials and Complexity.

Instruction

Project variation exists across Creative Design sections due to instructor expertise. Examples of classroom projects include; Classroom Improvement for Middle School Student, Logo Design, Automated Gingerbread Houses, LED Design, Dorm Redesign for the Visually Impaired and Robotics. While the projects completed have the potential to apply many aspects of design, little is known about how effective each project context is with concern to the measurements identified earlier. To this end, a series of "Defining Attributes of Creative Design Projects" was developed and aligned to common measurements (Table 2).

Table 2: Defining Attributes of Creative Design Projects

Defining Attribute	Example Topic(s)	Aligned Measurement
Design Thinking	Human-Centered Design	Creative Self-Efficacy and Creative Role-Identity; Creativity in Engineering Design (Artifacts)
Design Elements and Principles	Engineering Design Process	Ideation Capacity; Creativity in Engineering Design (Artifacts)
Design Skill Development	Spatial Thinking	Ideation Capacity; Creativity in Engineering Design (Artifacts)
	Technical Capacity	Creativity in Engineering Design (Artifacts)
	Tinkering	Ideation Capacity

Discussion

As creativity is highly valued by engineering professionals, it is logical to assume that teachers of K-12 engineering education should have capacity, capability and confidence in their own creative abilities.[3] Fostering the creativity of our future teachers within the context of design and engineering has become the primary purpose of the course Creative Design. This "Work in Progress" paper seeks feedback from engineering educators from across the country who study creativity. A possible research question for a larger study may be, "What effect does Creative Design have on developing creative capability, confidence and motivation of preservice integrative STEM and engineering teachers." Pilot data suggests students already see creativity as an ability and it will be important for us to measure whether they grow this ability by the end of the course. It will be interesting to see if students change their opinion on the characteristics of a creative person by the end of the course and discover that creative solutions are sometimes the most simple and appropriate given the constraints of the problem. Additional data suggests that the preservice teacher showed an increase in ideation capacity, and it is anticipated that there will be a similar increase in creative self-efficacy when compared to their peers from other majors on campus.

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