A Workshop for Shared Teaching Materials for Advanced Manufacturing

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Industrial Experience and Disciplinary Knowledge Impact on Creative Outcomes in a Making Context: A Case Study of Graduate Level Industrial Engineering Course

Abstract

Background: Design and creativity are essential elements of problem-solving.
Purpose: The purpose of the research presented herein is to identify the impacts of learning in different study programs on students' abilities to generate and implement creative design solutions.
Design/Method: An experiment was designed and conducted within the context of a semester-long graduate engineering course titled "Human-Centered Design and Manufacturing" at a large American public university. The experiment featured classroom data collection from an experimental cohort at four different stages of an intervention using a questionnaire. Results were then compared to those of a control group's.
Results: Preliminary results showed that students' systematic creativity learning lessened the differences in creative outcomes due to industrial experience and formal degree program differences.
Conclusions: Results from this study could help better prepare students for the ever-increasing interdisciplinary nature of engineering teams in different industrial settings all over the world. The intervention designed for this study will also help students more effectively transition from conceptualizing design concepts, to manufacturing those designs, and finally presenting results to key shareholders.

Keywords: Design teaching, critical thinking, creativity

1. Background

Creativity can be defined as "the ability to produce work that is both novel and appropriate" (Sternberg & Lubart, 1999). Natural creative ability is thought to be influenced by many factors, including personality, motivation, and training. In this study, the extent to which systematic creativity training can enhance students' creative design solutions is investigated. Unlike other similar studies, the emphasis in this investigation is on the impacts of formal learning and internship (industrial) experiences.

To inform the study design, a literature review was conducted. Manuscripts from the Engineering Village library published between 1977 and 2019 and retrieved for the combination of keywords "Creative Design Solutions" and ("Industry Experience", "Capstone", "Formal Education", "Internship or Co-op", "undergraduate") were considered. Datasets for all keyword combinations contained 316 manuscripts. Initial eligibility assessment of manuscripts for the corpus was conducted considering the title, abstract, and keywords. The second level of screening was conducted using the methodology and conclusions, where the number of references was then reduced from 316 to 20.

An overview of existing works in the area of fostering creative solutions with specific focus to internship/industrial experiences and formal curriculum is provided as follows. Within the field of engineering, Gosh (1993) hypothesized that the best way to foster creativity in undergraduate students is to carefully design challenging questions in exams and open-ended design problems. In Culvenor and Else's work (1997), undergraduate engineering students were trained and tested in creative thinking. A total of 42 fourth-year students participated in a one-day program in creative thinking training based on the Six Thinking Hats technique. Students were assessed on their abilities to generate alternative safety solutions and prioritize safety solutions given a list of options (de Bono, 1985). A study on undergraduate engineering students was conducted by Joshi and Sinha (2019), where the researchers investigated the possibilities of facilitating innovative problem solutions by implementing the 7C's design process. A recommendation was design education in non-design disciplines could lead to exploration and creative design solutions. For example, Wang (2007) discussed the effect of employing multimedia courseware in inspiring the creative thinking of engineering students. He concluded that it is possible to improve individuals' creative capability through training. To adapt to the socioeconomic environment, Haen et al. (2012) developed the CBiRC REU program, which aimed to develop creativity, innovation, and adaptability in chemical engineers during a 10-week immersion to laboratory research, workshops, seminars, and interactions with professional staff. The benefit of connecting students and industry has also been studied widely. Zbigniew Kols and Hanna Sawicka (Kols & Sawicka, 2007) developed an environment where students from five different countries and companies collaborate to develop innovative solutions. The collaboration brings different benefits to students including exposure to different universities and potential employers as well as getting to know interesting personalities among peers.

A capstone design experience is another opportunity to connect students with industry. The school of Electrical and Computer Engineering at the University of Oklahoma designed a course that structures a creative design environment to expose students to the real challenges of professional environments and promotes creative need-based designs (Crain & Tull, 2004). Reissman et al. (2017) also proposed a new capstone course for Mechanical Engineering students at the University of Dayton, which emphasizes the application of physics-based and data mining toward open-ended project prompts. Peter Idowu (2004) presented a study about the pre-capstone course at Penn State Harrisburg to solve the lack of clarity students have in developing project ideas. In this study, researchers concluded that a pre-capstone course enabled students to communicate effectively. Elvin Shields (2007) studied the effect of capstone engineering design experience in fostering creativity.

Various methods and techniques can assess students' creativity. For example, Setiadi et al. (2013) assessed students' creativity among undergraduate art and design students using a computer software creativity simulation. Creativity happens when designers consider themselves as users (Goncher, Johri, & Sharma, 2010). In a study by Clark, Stabryla and Gilbertson (2018), authors targeted the need for enhanced engineering curricula to foster creativity in students. They considered the effect of active learning and the design thinking process on driving creative and sustainable engineering design solutions.

As per the literature summarized above, we observe that to a large extent researchers have not studied the effect of prior industry experience on creative problem-solving. This paper aims to investigate whether prior industry experience or field of study could affect students' creative thinking ability. Considering the different types of training students could receive in their life, (formal and informal (e.g., via internships)), answers to two research questions are targeted:

(1) Are students' self-efficacy levels in generating and implementing creative design solutions affected by prior industrial experience?

(2) Are students' self-efficacy levels in generating and implementing creative design solutions affected by their undergraduate/graduate degree program?

The hypothesis is that formal learning through enrollment in, and completion of degree programs trains different ways of problem-solving in students and potentially impacts creativity. Moreover, creative problem solving might be impacted by exposure to industrial settings through internships; to the best of current knowledge, these variables have not been included in prior studies of creativity, specifically involving engineering students.

Therefore, herein, the focus is on how various disciplines consider and approach creativity and design, as well as how industrial experiences affect graduate students' creative outcomes. This work can be seen related to "Cultural Historical Activity Theory (CHAT)," which was addressed by many researchers (please refer to paper by Foot (2001) for a summary). For example, in the paper by Hinkle, Christopher, & Koretsky (2019), the authors investigated three student engineering clubs at a large American public university, where researchers found that a confluence of elements leads to a fundamentally different activity system in each club. Activity, in this context, refers to a chain of actions (purposeful) and operations (routine and involving methods for accomplishing actions). Because actions and operations change across disciplinary boundaries, we opine that the approach to creativity and design may change. Understanding these differences could better prepare students in the ever-increasing interdisciplinary nature of an engineering team, while helping students develop more creative designs. This research could affect most engineering disciplines that involve engineering design, as well as industrial design and human-computer interaction disciplines.

The rest of this paper is organized as follows: **Section 2** presents the research design and implementation. **Section 3** describes the subjects and the context. **Section 4** summarizes the experimental results and their analysis; concluding remarks are presented in the last section, **Section 5.**

2. Research Design and Implementation

A semester-long graduate engineering course titled "Human-Centered Design and Manufacturing" was developed and implemented. The experimental group had 24 members divided into eight teams. Groups were set to be multidisciplinary where the students varied from the following disciplines: industrial engineering, human-computer interaction, aerospace engineering, mechanical engineering, and agricultural and biosystems engineering. Furthermore, knowing/learning through the fulfillment of degree programs and industrial experiences was specifically concentrated on by this study.

It is expected that the students will transition from intellectualizing design ideas that combine human factors principles to manufacturing those same designs, and finally to presenting those designs and products to key shareholders. The Human-Centered Design and Manufacturing course was envisioned to help with this transition of ideas to tangible designs. Moreover, the same course context provided a venue for experimental investigation to supply our knowledge on how various disciplines consider creativity and design, and how industrial experiences impact graduate students' creative outputs.

Overall, it is anticipated that students' systematic creativity learning will reduce the differences in creative output due to formal degree program differences and industrial experience. As a systematic creativity tool, TRIZ was included in the curriculum. TRIZ is a Russian acronym which translates to Theory of Inventive Problem Solving in English. TRIZ involves using a specific method to describe a problem with a set of design parameters, which may be then used to connect design principles shown to be successful for problems involving the same parameters. While success of TRIZ has been shown in enhancing engineering students' creative outcomes (Vargas Hernandez et al., 2013), prior works have not studied the potential impacts of industrial experiences and students' chosen program of study simultaneously.

Furthermore, low-cost 3D printing solutions may reduce the students' inhibitions, and thereby increase students' self-efficacy. Students are expected to design, test, print, and reiterate through multiple designs without worrying about the cost of raw material, machining, and an experienced manufacturer. Overall, in relation to the research questions presented in Section 1, it was hypothesized that students with higher levels of industrial experience will have higher self-efficacy levels in generating and implementing creative design solutions. Similarly, we also hypothesized that students with engineering backgrounds would have a higher self efficacy in generating and implementing creative design solutions.

The following learning outcomes are what the course was designed around: 1- Be able to apply TRIZ problem solving to novel problems, and Manufacturing Design Principles and Human-Centered Design principles to projects, 2- Be able to identify, formulate, and solve engineering problems and to use the techniques, skills, and modern engineering tools necessary for engineering practice, and 3- To understand the ethical responsibility.

Nine lectures were developed, where each was designed to last three hours (with the lab component), and four labs were held throughout the semester that were designed to reinforce key learning concepts. The lectures and the labs are shown in Table 1.

Table 1. The nine lectures and the four labs that were held throughout the semester.

The lectures	The labs
1- Introduction to Engineering Design. 2- Engineering Creativity and TRIZ. 3- Introduction to Rapid Prototyping. 4- Human-Centered Design Approach. 5- Human-Systems Engineering. 6- Machinability-Manufacturing Design Principles. 7- Product Analysis and Ergonomic Testing. 8- Return on Investment (ROI). 9- Expected Outcomes.	1- Engineering creativity and TRIZ. 2- Introduction to Rapid Prototyping (RP), Anisotropy, Infill, and Strength. 3- Product Testing. 4- Moving from design for rapid prototyping to design for manufacturing.

Student participants (subjects) completed classification (demographics) and self-efficacy surveys and a modified unusual uses task. The modified unusual uses task and self-efficacy survey were administered several times during the semester – at the end of the first class (Assessment 1), after project 1 (Assessment 2), after project 2 (Assessment 3), and at the start of the final design competition (Assessment 4). Self-efficacy was measured as students' responses to a 0-100 scale where they recorded their confidence level in being able to complete a specific task.

3. Subjects and Context

Because data collection required the use of graduate students of different majors who registered for the same course, samples sizes were small. The characteristics of the subjects of the two groups are shown in Table 2.

Table 2. The characteristics of the subjects of the experimental and control groups.

	Number of members	Average age	Internship experience	Full-time industrial experience.
The experimental group	24 members (19 males, 5 females)	24.21 years (SD* = 4.11 years)	4.63 months (SD = 3.83 months)	0.853 years (SD = 2.96 years)
The control group	14 members (12 males, 2 female)	31.29 years (SD = 8.68 years)	3.93 months (SD = 5.09 months)	5.62 years (SD = 7.20 years)

*SD: Standard Deviation

4. Experimental Results and Analysis

The self-efficacy average increased across 19 items in the experimental group vs. the control group. Figure 1 shows an average increase (from the beginning of the course to its end) of 35.70% (minimum of 16.61% increase; maximum of 55.61% increase) compared to the 30.60% baseline of the control group.

All students had an average self-efficacy increase from Assessment 1 to Assessment 4; taking four items as examples: the item (survey item) "I come up with creative designs" had an average increase of 23.85%; the item "I am comfortable designing for rapid prototyping" had an average increase of 36.54%; the item "I am comfortable designing for manufacturing" had an average increase of 31.92%; and the item "I am comfortable using 3D printers" had an average increase of 35.92%. Table 3 summarizes the ANOVA results for these four items.

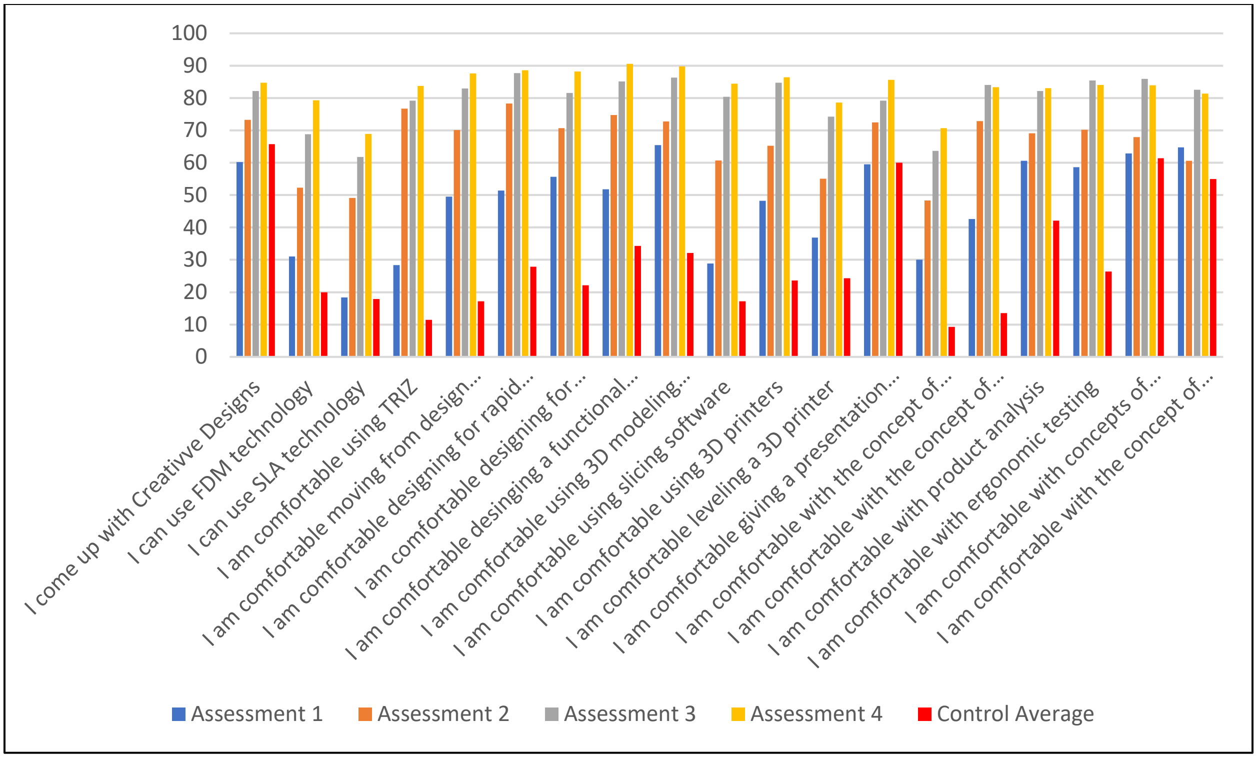

Figure 1: Self-Efficacy Average Increase Across 19 Items (Experimental Group vs. Control Group).

Table 3: ANOVA results for the four items.

Item	Source of Variation	*SS	#df	&MS	$P-value
I come up with creative designs	Between Groups	8841.346	3	2947.115	6.58E-05
	Within Groups	36157.69	100	361.5769	
I am comfortable designing for rapid prototyping	Between Groups	15102.88	3	5034.295	1.87E-05
	Within Groups	73052.88	103		
I am comfortable designing for manufacturing	Between Groups	15102.88	3	5034.295	1.87E-05
	Within Groups	54450	100	544.5	
I am comfortable using 3D printers	Between Groups	23587.5	3	7862.5	3.09E-07
	Within Groups	60488.46	100	604.8846	

*SS: Sum of squares; #df: Degrees of freedom; &MS: Mean squares; $P-value: Significance level.

Figure 2 shows the self-efficacy for the mentioned four items (Experimental group vs. Control Group). On the y-axis, the average of self-efficacy ratings for the four items from Appendix was shown. The x-axis listed the 24 participants of the experimental group. For “I come up with creative designs”, the experimental group rated their self-efficacy 18.91% higher than the control group (Experimental Mean = 84.62% vs. Control Mean = 65.71%). Statistically significant results were obtained with a p-value of 0.0019. The experimental group, for “I am comfortable designing for rapid prototyping”, rated their self-efficacy 60.99% higher than the control group (Experimental Mean = 88.85% vs. Control Mean = 27.86%). Statistically significant results were also obtained with a p-value of 8.33743E-06. For the item “I am comfortable designing for manufacturing”, experimental group rated their self-efficacy 66.32% higher than the control group (Experimental Mean = 88.46% vs. Control Mean = 22.14%). A p-value of 6.69829E-07 was achieved for this significance test. The response for the item “I am comfortable using 3D printers” was 61.57% higher than the control group (Experimental Mean = 85.54% vs. Control Mean = 23.57%). Results were again statistically significant, with a p-value of 3.36E-06.

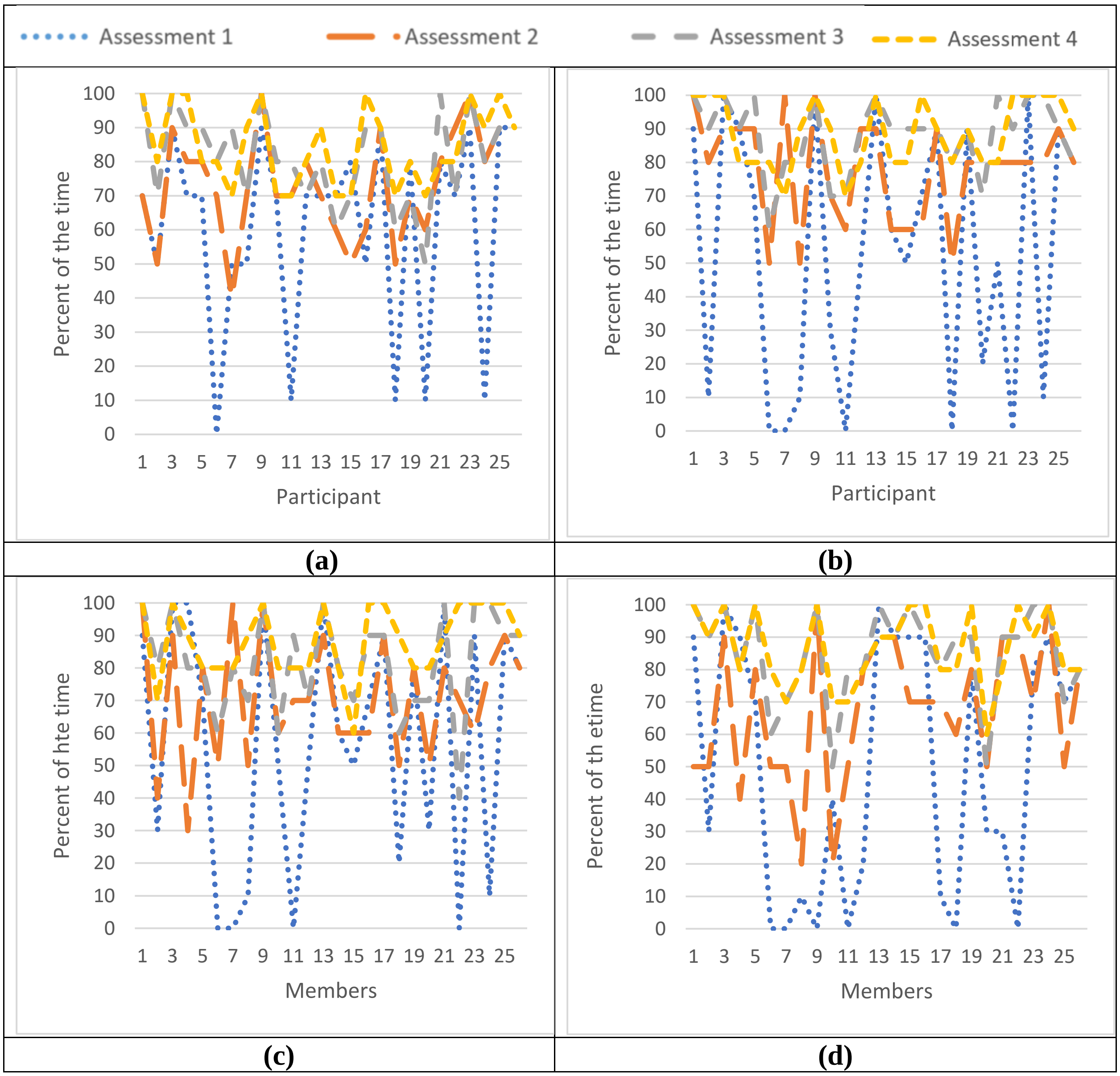

Figure 2: The Self-Efficacies for four items (Experimental group vs. Control Group.): (a) “I come up with creative designs,” (b) “I am comfortable designing for rapid prototyping,” (c) “I am comfortable designing for manufacturing,” and (d) “I am comfortable using 3D printers”.

Finally, through regressions, the impact of the discipline and the impact of the industrial experience on Assessment 4 results were investigated. Assessment 4 results were used for these analyses because through the described laboratory and lecture sequence, it was hypothesized that at that time in the semester the studied variables would result in the smallest variation in the results. For the first question, disciplines were coded simply as engineering (1) versus non-engineering (0) because the data set was not large enough to further divide group into various engineering majors. Results showed that the impact of the discipline was not significant. However, those with engineering backgrounds had higher assessment 4 scores. For the second question, number of internships was used as a proxy for industrial experience. Regression results showed a significant impact of industrial experience on assessment 4 results for a α=10% (p= 0.085), and R^2=0.124.

5. Conclusions

This paper discussed how various disciplines consider and approach creativity and design, and if industrial experience might impact graduate students' creative outputs. An experiment on a semester-long graduate engineering course titled "Human-Centered Design and Manufacturing" at a large American public university was developed and implemented. Data was collected from an experiment and a control group of 24 and 14 graduate students, respectively. This paper summarized the select assessment results comparing experimental and control groups.

It was hypothesized that in a creative problem-solving state, learners' industrial experiences and formal education will affect their self-efficacy for generating and implementing solutions and eventual creative outputs. It was expected that systematic creativity learning by students will reduce the differences in creative output due to industrial experience and formal degree program differences. Low-cost 3D printing solutions could reduce the students' inhibitions, and thereby increase students' self-efficacy. Students were expected to design, test, print, and reiterate through multiple designs without worrying about raw material or machining costs. The statistical analyses focused on the experimental group, and revealed that creativity training with hands-on prototyping elements can reduce the impacts of disciplinary differences and industrial experience. Comparisons to the control group are also provided.

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Disclosure statement

No potential conflict of interest was reported by the authors

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Appendix

Please rate how certain you are that you can accomplish what is being asked at each of the levels described below.

Rate your degree of confidence by recording a number from 0 to 100 using the scale given below

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately can do					Highly certain can do

Place an 'x' on the line that best describes your confidence level.

	Confidence (0-100)
I come up with creative designs 0% of the time	________
" " " " " " " 10% " " " " " " "	________
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Confidence (0-100)

I am comfortable designing for rapid prototyping 0% of the time __________
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Confidence (0-100)

I am comfortable designing for manufacturing 0% of the time __________
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Confidence (0-100)

I am comfortable using 3D printers 0% of the time __________
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