Does an Open-Ended Design Project increase Creativity in Engineering Students?

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***Abstract*—Many schools are incorporating project-based interdisciplinary exercises into their engineering curriculum in order to develop the qualitative and quantitative skills simultaneously. It has been shown that introducing design in a freshman engineering course has a positive impact on retention, stimulates interest in engineering and enhances communication, teaming and time management skills. But can design also improve creativity? Or, to be more specific, would an open-ended design project improve creativity in engineering students? In the fall of 2015, an innovative design project was used in a first-year engineering course at Michigan Technological University. Students were given the task to develop a prototype of a new product or an improvement on an existing product. While some of the tasks were defined throughout the semester, the product they created was completely up to the team. It was thought that the open-ended nature of the project and the product itself being new or innovative would help improve their creativity. Students completing this project were given a 55 question pre- and post-assessment. This assessment included several measures of general creativity and entrepreneurial intentions: Oreg's Resistance to Change Scale (RTC), the Curiosity and Exploration Inventory (CEI), and the Zampetakis & Moustakis Scale (Z & M Scale).This paper focuses on the development and evaluation of this open-ended design project for first-year engineering students and the results of the various measures of creativity.** **Keywords—creativity; engineering education; project-based learning**

I. Introduction

Historically, high school students who are "good at science and math" have been encouraged to go into engineering. Engineers are known for their ability to take a problem, break into parts and find a viable solution. To complete this work, they must be able to apply concepts from math, science and engineering classes. The National Academy of Engineering (NAE) has added to their goals for the engineer of 2020 that engineers will look at the social and economic impact of their designs, along with utilizing a "creative process" [1]. It is this aspect of creativity that this work investigates with respect to first-year engineering design projects.

Innovation or entrepreneurship has been increasingly used in engineering courses with a large design component. When students develop a design idea, some students or teams regardless of experience or academic standing, will just meet the requirements, while others will be innovative or creative. In a study completed at the University of Massachusetts, Dartmouth, first-year and seniors were given design problems for their respective classes. The teams developed their design solutions using the 6-3-5 method. The basic 6-3-5 method involves six team members developing three ideas each in five minutes. Each idea is critiqued by the team members. The design classes were further divided for each group of students into classes that emphasized innovation and those that did not. "Originality" of the designs was evaluated using a 5 point scale with "0" being a "common" design and 10 being "innovative". Regardless of grade level (first-year or senior), the students who were exposed to the process of innovation, developed more original designs than the students who did not have this exposure. The first-year team whether they were exposed to innovation concepts or not had more originality in their designs that the senior level teams. The first-year students had designs that focused on the idea and functionality, while the senior designs focused on concepts that were feasible, but not innovative [2].

Teaching innovation and entrepreneurship requires slightly different methods than traditional engineering design courses. In these classes, students not only have to learn about creativity, they also need to learn how that relates the entrepreneurship and develop a thinking process that emphasizes creativity, innovation and promotion. Entrepreneurship, through the Enterprise Program, at Michigan Technological University, has been included as a path through the engineering program since 1999. Students begin the program as early as sophomores and can participate through their senior year. This program focuses on the development of entrepreneurial skills through working on student led companies. The Enterprise Program has business, teaming, communication and design components. Students learn how small businesses operate and how innovative engineering design occurs [3].

The challenge is, once a university develops course materials in innovation and/or entrepreneurship, what methods are valid to evaluate their success? One method is the Creative Engineering Design Assessment (CEDA). This assessment looks at creativity in engineering specifically to whether or not a design is useful and original [4]. This tool was used to

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evaluate the creativity in engineering design for first-year engineering students at university in the mid-west. Within this course, students completed a functional roller coaster. Students completed the CEDA at the beginning and the end of the class. When the results were analyzed, the female students had an increase in creativity, but male students actually showed a decrease in creativity. This phenomenon had been found by other researchers in another study, but the reason why it occurred was unknown. It was hypothesized that the development of engineering skills may impact creativity over the short term. The authors stated that sometimes when an individual learns a new skill, other skills may actually decline while the person is applying and using the new skill. As the skill level increases, the other skills return to their previous level or increase [5].

Teaching creativity can be challenging, especially in engineering courses because engineering students sometimes do not associate engineering with creativity. To assess if students' creativity skills were developed in seven separate courses, interviews were completed with instructors to determine course pedagogy and with students to determine their perceptions of how creativity was included in the class. Additionally, student surveys and course materials were analyzed. Most of the classes analyzed focused on the computational and traditional aspects of engineering courses. The data showed the more time could be allocated towards encouraging students to explore options and reflection which greatly enhance creativity [6].

II. FIRST-YEAR ENGINEERING AT MICHIGAN TECHNOLOGICAL UNIVERSITY

At Michigan Technological University, engineering students begin their studies within the first-year engineering program. This program includes two paths: Calculus-ready and Pre-Calculus/College Algebra ready and are shown in Fig. 1 below. In the Calculus-ready track, students complete two classes ENG1101 (Engineering Analysis and Problem Solving) and ENG1102 (Engineering Modeling and Design). The other path consists of three classes: ENG1001 (Engineering Problem Solving), ENG1100 (Engineering Analysis), and ENG1102 (Engineering Modeling and Design).

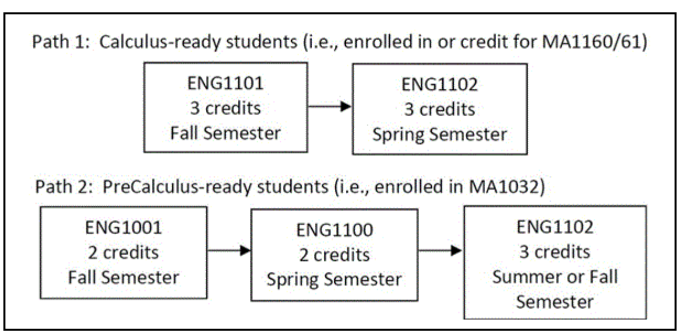

Fig. 1. First-Year Engineering Program Flowchart [7]

Within both courses of the calculus-ready sequence, and the last two courses of the pre-calculus track, student teams complete a significant design project. It has been shown that introducing design in a freshman engineering course has a positive impact on retention [8], stimulates interest in engineering [9], and enhances communication [10], teaming [11], and time management skills [12]. What we do not understand as engineering educators however, is if teaching design also improves creativity and innovation in our students. This study examines how an open-ended design project with prototyping influences creativity in first-year engineering students when common measures of creativity are used.

During the 2015-2016 academic year at Michigan Tech, first-year engineering students were placed into their introductory engineering course based upon their math skill (ENG1001 or ENG1101). Subsequently, student teams of approximately four students each were created and assigned a semester-long design project. Five of fifteen sections of ENG1101 (295 students, 72 teams) used an innovation design project. For this project, students were tasked to develop a physical prototype of either a new product or an improvement on an existing product. For the purposes of this project, a product was defined as "a good, service, or idea consisting of tangible and intangible attributes that satisfies consumers and is received in exchange for money or some other unit of value" [13]. Throughout the semester, the students were responsible for completing the tasks shown in Table I below. While some of the design criteria were defined throughout the semester, and were instructor-specific (e.g. the use of biomimicry or the principles of green engineering), the product that the students created was completely up to the team.

TABLE I. ENG1101 INNOVATION DESIGN PROJECT TASKS

Project Task	Description
Proposal	Discusses project goals, product idea, similar products, the consumer need being addressed, target market, and management plan for the project.
Team Interview	Team meeting with instructor to address questions raised in proposal.
Proof of Concept	Report that demonstrates the product's fit (solution matches problem), form (detailed sketch or prototype of design), and function (demonstration of how it works) and estimates production costs.
Simulation	MATLAB program that estimates the startup costs of a small business to build and sell the product.
Feasibility Report	Describes final product and discusses feasibility of continued development.
Pitch Presentation	Presentation to classmates to "pitch" product to class.

III. METHODS

Students participating in this project were given a 55 question instrument that included several measures of general creativity and entrepreneurial intentions: Oreg's Resistance to Change Scale (RTC), the Curiosity and Exploration Inventory (CEI), and the Zampetakis & Moustakis Scale (Z& M Scale). In addition to these scales, there were 20 questions developed as part of an NSF CCLI Phase I proposal (DUE-0836861) to measure creativity in engineering [14]. As these were not part of a validated scale, they were not used in this analysis. This assessment was given twice: once at the beginning of the semester and then again after the project was completed. A total of 86 students completed both assessments for a response rate of 29%.

The Resistance to Change Scale (RTC) quantifies an individual's resistance to change. Typically, the more resistant a person is to change, the less creative he/she is. The four-factor RTC, which was used in this analysis, consists of 18 questions with answers based on a 6 point Likert scale. This scale measures four factors (Routine Seeking, Emotional Reaction, Short-Term Thinking, and Cognitive Rigidity) and has been shown to be negatively correlate with creativity [15]. For example, a student who is more likely to seek out routine, reacts negatively to change, focuses on the short-term issues related to change rather than long term benefits, and does not change their mind, would be less likely to exhibit creative tendencies. We expected that students should decrease in all factors of the RTC scale as they become more creative.

Curiosity has been shown to be positively correlated with creativity [16, 17]. As such, the second tool used was the Curiosity and Exploration Inventory (CEI). The CEI was developed to assess a person's curiosity. This is a seven-item survey with two factors: Exploration and Absorption. Exploration questions were designed to assess an individual's desire to explore challenging experiences, while the Absorption factor assesses an individual's absorption in these challenging or novel experiences [17]. It was expected that students who experienced gains in creativity, would also experience gains in curiosity.

The Zampetakis & Moustakis Scale (Z & M Scale) quantifies how creativity and entrepreneurial intentions are linked. The survey contains 11 questions within four factors. The factors focus on a) student perceptions of their own creativity, b) positive perceptions of creativity within the University Environment, c) positive perceptions of creativity within their family, and d) their propensity toward entrepreneurship. The questions for the University Environment were modified to focus specifically on their engineering coursework rather than the university as a whole. The Z & M scale was evaluated through over 180 undergraduate students completing the survey at two technical universities in Greece. The study showed that there was a positive effect of a student's perceived creativity on their tendency to be interesting in entrepreneurship, which correlated well with a family environment that supported creativity. University environment did not impact entrepreneurial intentions [18]. It was expected the open-ended nature of this engineer design project should positively affect their perceptions of their own creativity, the positive perceptions of creativity within their engineering course, and their entrepreneurial intentions. No changes were expected in the family perceptions of creativity.

IV. RESULTS

Overall, 72 student teams participated in this study. While the specific project products were diverse among the groups, four general themes emerged that summarize the product types developed by the teams. This distribution is shown in Fig 2 below.

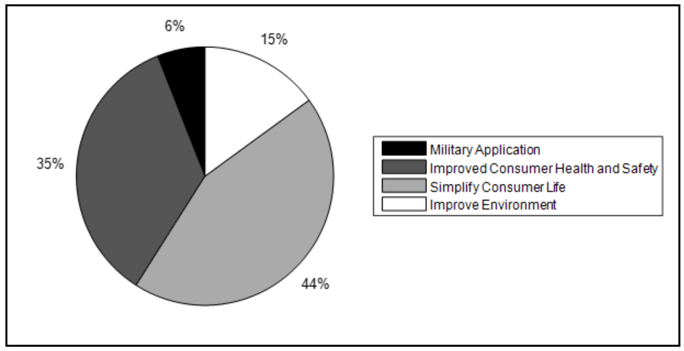

Fig. 2. ENG 1101 Design Project Ideas

Most of the project ideas were intended to improve the consumers' health and safety or simplify the consumers' life. Nearly half (44%) of the teams developed a product that specifically focused on making life easier in some way. For example, some products focused on dormitory life and included ideas to facilitate access to lofted sleeping systems or keyless entry systems into dorm rooms to eliminate the need for a key. Other products focused on improving consumer health and safety (35%). In this category, several products were developed to improve traction on slippery surfaces, improve vision in dark or low-visibility locales, enhance the protective capabilities of helmets, and use biomaterials to make surfaces that reduce microbial activity. In the category related to improving the environment (15%), 6 of the 11 student groups generated ideas that focused on providing a sustainable source of potable water to various contexts (urban areas, developing countries, etc.) via filtration, solar energy or some alternative innovation. The other teams in this category demonstrated a diverse range of products, with innovations such as: more efficient plywood, a solar-power generating garden for rooftops, a completely biodegradable coffee cup, and a heat exchange system for the university campus. The final category, military applications (6%), had four student projects that centered on topics like enhanced body armor and weaponry systems.

To analyze our survey results, we used a paired sample t-test in SPSS to determine the change in the pre- and post-values for each of the creativity scales mentioned above as well as the individual factors. These results are shown in Table II below. As expected, there were significant differences with the Z & M scales on several factors. Students ranked all Z&M scale factors higher on the posttest, with their own creativity, entrepreneurial intentions and the overall scale as significantly higher. It is interesting to note that, while not statistically significant, the students perceived an increase in both positive perceptions of creativity within their engineering coursework and family environment.

TABLE II. ENG1101 INNOVATION DESIGN PROJECT TASKS

Scale	Factor	N	Δ Mean (Pre – Post)	p
Z & M	Own Creativity	86	-0.628	0.000[a]
	University Environment	83	-0.169	0.509
	Family Environment	85	-0.424	0.079
	Entrepreneurial Intentions	85	-0.600	0.005[a]
	Total	81	-1.889	0.000[a]
RTC	Routine Seeking	81	0.000	1.000
	Emotional Response	83	0.530	0.167
	Short Term Thinking	82	-0.134	0.686
	Cognitive Rigidity	79	-0.684	0.032[b]
	Overall	73	0.096	0.900
CEI	Exploration	83	0.036	0.894
	Absorption	83	-0.373	0.076
	Overall	81	-0.333	0.385

[a] $p<0.01$
[b] $p<0.05$

It was predicted that there would be positive gains (in this case a lower score between pre- and post-) within the Resistance to Change scale (RTC). However, the results were not what we expected. More specifically, there were gains within the Emotional Response factor, which would indicate that students are less stressed out by change at the end of semester than the beginning. However, there were statistically significantly higher scores on the Cognitive Rigidity scales, which would seem to indicate that students are less likely to deviate from a course of action or change their minds than the beginning of the semester. This is not what we expected to see and is something we need to investigate further. There were no significant changes in the Curiosity and Exploration inventory, although the Absorption factor is close to significance. This would seem to indicate that students at the end of the semester get more absorbed in challenging tasks. This would be something we would expect to see as students become more curious about a task.

V. CONCLUSIONS

An open-ended design project where student teams developed a new product was used in the first-year engineering program at Michigan Tech. Seventy-two teams participated in this project and created products for a variety of applications. We used three different measures to assess changes in creativity, curiosity, and entrepreneurial intentions. As expected, there were statistically significant positive gains in the Z&M scale and specifically factors related to individual creativity and entrepreneurial intentions. Although not significant, there were slight gains in absorption of students on challenging tasks, and student perceptions of creativity in engineering coursework. Surprisingly, while these results suggest that this project has positively affected student's creativity, their results on the Resistance to Change (RTC) scale seem to indicate otherwise. While few changes exist in this scale, there is a significant increase in the student's cognitive rigidity. This seems to indicate conflicting results. Are our students becoming more creative, but also more set in their thinking? This could be due to learning about a concept and then becoming "rigid" in their thinking until they become comfortable [5].

In our future work, we would like to explore the effect of the design process on creativity. This would require a longer study period. We think the students' rigidity would increase over the short-term (in ENG1101) and then, as they become more familiar with engineering problem solving, it would decrease. This decrease should occur in ENG1102 where students apply their design process skills to a new project that they choose.

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