Exploring Differences in Perceived Innovative Thinking Skills Between First Year and Upperclassmen Engineers

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***Abstract*—This paper addresses the question of how undergraduate engineering students view the concept of innovation and their own innovative abilities. The study took a mixed methods approach that included both a survey and focus groups to explore this question. The survey revealed significant differences in how fourth year and first year students rated their innovative thinking skills, where the fourth year students believed themselves to be more innovative. To understand why these differences exist, the research team conducted separate focus groups with upperclassmen and first year students. The two age groups defined innovation similarly, but the first year students associated innovative thinking more closely with engineering design. The upperclassmen mostly viewed their innovative thinking skills through their experiences in extracurricular activities. These differences suggest a need to incorporate innovative thinking more intentionally into engineering classrooms.**

Keywords—innovation; innovative thinking; first year students

I. Introduction

Innovative thinking has been identified as a key factor in growing a modern economy. Several recent reports have called for increases in education on how to think innovatively. In turn, universities are considering how to do this effectively while also ensuring graduates meet disciplinary content standards [1]. Engineering education in particular has highlighted the need to increase creativity and entrepreneurship skills in program graduates [2], [3]. However, few studies have explored the perspectives of engineering students on the topic of innovation. In order to better teach innovative thinking, it may be useful to understand how students think about innovation, whether they perceive their innovative thinking abilities to increase during their undergraduate career, and what experiences impact their ability to think innovatively.

II. Literature Review

A. *Defining Innovation*

After analyzing more than 60 definitions of the word "innovation," Baregheh, Rowley, and Sambrook identified the following unified definition: "Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service, or processes, in order to advance, compete, and differentiate themselves successfully in their marketplace" [4]. This definition captures the idea of innovation as a process, which is a common theme in the engineering education literature [5]–[9]. While creativity is often associated with innovation, it has been recognized as an early part in the innovation process [5], [10], [11]. Precise steps in the process vary from paper to paper, but common stages include problem identification, ideation, solution identification, experimentation, and implementation [5], [7], [10], [11].

Within engineering education, innovation often focuses on the idea of coming up with an innovative design. Two characteristics of innovative designs are constant throughout the literature: originality (also called novelty) and practicality (also called usefulness or appropriateness) [5], [12]–[14]. Originality is discussed most thoroughly, and several types of designs are highlighted, stemming from a brand new product to the addition of a new feature to an existing product [2], [6]. Though originality is agreed to be necessary, classifying designs as original or not is more challenging. Several studies have created rubrics to compare the originality of student designs, ranging from classifications of "common" or "dull" to "innovative" or "genius" [5], [12]. However, few attempts have been made to define what constitutes a truly original design.

Entrepreneurship is also commonly tied with innovation in people's minds and in the literature. It is generally agreed that innovation is an important foundation to entrepreneurship [6], [10], [15], however entrepreneurship is viewed more as the business application of an innovative idea [6], [10], [13]. At the same time, entrepreneurship involves more people, leadership, and team skills than innovation alone, making it important to identify which concept is the goal in a particular educational setting [16]. Entrepreneurship has been highlighted as a key part of engineering innovation, because an innovative product design is no good if it is not successfully made available to customers [3], [13].

B. *Teaching Innovation*

Many studies have worked to identify skills associated with innovative engineering design. Several authors have identified observation, big picture thinking, and problem finding as key starting points [5], [7]–[9], [11], [17]. Divergent thinking, or the ability to identify a wide variety of different solutions to a problem, is highlighted as an important characteristic in the ideation phase of design [2], [5], [9], [18]. After identifying possible solutions, the abilities to experiment, prototype, and make iterative improvements allows engineers to hone a design to a final solution [6], [8], [11], [17], [18]. Throughout the process, collaboration [7], [10], [11], [17], risk-taking [2], [8], [19], and self-efficacy [2], [20] have also been identified as helpful to the innovative design process.

Despite the many skills associated with innovative design, it is generally agreed that these skills can be taught [8], [9], [17], [21], and universities have explored different ways of doing this in engineering classrooms. Some have focused on developing design skills specifically, through competitions [9], collaborative activities [7]–[9], open-ended projects [2], [7], [12], and providing feedback from mentors and peers [2], [18], [22]. Others have looked more to challenge students' thinking processes through teaching ideation strategies [12], [21], reflection [18], [21], [22], and interdisciplinary work [2], [9], [11]. Researchers have also found that extracurricular activities can support students' development of innovation skills linked to entrepreneurial outcomes [16] and innovation self-efficacy [20].

Nonetheless, there is debate about whether or not the typical college engineering experience enhances student innovation. While lack of knowledge has been shown to limit creativity, increasing knowledge does not always increase innovation [12]. More knowledge does help with the generation of more different design options, but these may not be original. On the contrary, learning about previous engineering designs and accepted methods can cause design fixation, which causes students to imitate designs they have learned about [11], [12], [18]. Advanced skill levels may lead to scripted thinking, as found in two studies where senior engineering students produced less innovative designs than freshmen, particularly on more open-ended tasks [12], [23]. While some studies have found that seniors gather more problem information than underclassmen [24], [25] and create higher quality (i.e. practical and feasible) solutions [25], [26], these studies did not consider the originality of the solutions. Feedback from industry has also suggested that engineers are not graduating with sufficient innovative thinking skills [2]. .

C. Student Perspectives on Innovation

Fewer researchers have explored the perspectives of engineering students on innovation. One paper highlights anecdotal evidence that students feel they are not being taught innovation, saying they want more open-ended projects and sought out extracurricular activities to gain such experience [2]. Another study looked at the impact of a specific extracurricular design team on students' perceived innovation and design skills, and found them to increase between pre- and post-surveys [20]. Interviews in the same study revealed that students enjoyed the freedom of the extracurricular experience, which provided peer feedback and collaborative learning rather than "a teacher breathing down your neck" (p. 321). One pilot study asked students in a first year engineering course to define innovation and identified themes similar to those highlighted in the literature: creativity, usefulness, feasibility, viability, and desirability [27]. At the same time, however, another study found that engineering students perceived their educational environment to provide only one out of ten factors that encourage creativity [28]. More information about how engineering students conceptualize innovation, view their own innovative thinking skills, and experience the current environment of engineering education could inform instructors' efforts to teach these skills in engineering classrooms.

The purpose of this study was to learn whether undergraduate engineering students view themselves as innovative and whether these perspectives differ by class year. This study also examined how undergraduate engineering students define innovation and how these perspectives differ between first year and upper class students. We sought to understand what influences students' perceptions of innovation in order to provide recommendations for educators hoping to develop innovative thinking skills in their students.

III. Methodology

This study used a mixed methods approach that included a survey followed by focus groups. The survey was conducted to examine whether there were differences by class year in students' perceptions of their innovative thinking ability. Focus groups were held to explore in more detail how students defined innovation and viewed their innovative thinking ability.

A. Instrumentation

Questions in the online survey asked students to rate themselves in comparison with their peers on several items including the ability to identify, design, and prototype innovative solutions and the ability to communicate those designs and solutions to others. For all of these items participants could select 1=Well below Average, 2=Below Average, 3=Average, 4=Above Average, 5=Well above Average. Participants could also select "Do Not Know/No Experience."

The procedures of a mixed method design suggest that the quantitative data should lead the research design and the development of qualitative inquiry [29]. In this context, the research team created a focus group interview protocol to use with the undergraduates after the survey items were reviewed. The focus group questions were designed to explore how undergraduate engineering students define innovation and whether that understanding impacts their perceptions of their own innovative abilities.

B. Data Collection

The online survey was administered in the middle of the spring semester to 7,402 engineering undergraduates by an email invitation. After one week, students received a reminder if they did not complete the survey. In total, 795 students submitted responses and of those 595 were complete responses used for this analysis. The focus groups were advertised separately to first year students and upper class students (i.e. students in their junior and senior years) by way of email invitations. Students who elected to participate in the focus groups were offered a small meal as an incentive to participate, and the focus groups lasted about one hour. In total, 43 first year students participated in five focus groups and nine upper class students participated in two focus groups.

C. Validity and Reliability

Several steps were taken to establish the reliability and validity of the survey. To establish construct validity [28], a group of experts reviewed the initial survey questions that were developed using Zheng's framework of innovation [10] and the theories presented in Dyer, Gregersen, and Christensen's work [17]. Following the panel's review and feedback, a pilot survey was conducted in spring of 2015. For the Likert scale questions, a factor analysis was conducted and internal consistency analyses were performed using Cronbach's alpha. The factor analysis demonstrated a one factor structure and factor loadings that exceeded .60. The Cronbach alpha scores ranged from .87 to .82, indicating that there was a high internal consistency among the items. In order to establish the reliability [30] of the survey among the population used for this study, Cronbach alpha was conducted again on their responses and similar scores were received on the items ranging from .87 to .82.

The focus group questions had also been piloted as parts of previous focus groups with different student populations. Adjustments were made to the questions before use in the current study. Triangulation between the survey and focus group results further supported the themes identified through analysis of the focus group transcripts [29].

D. Data Analysis

A series of ANOVA analyses allowed for an initial exploration of differences by class year in respondents' perceived innovative thinking skills. The ANOVA was used to compare the mean scores of respondents on the survey items measuring whether they saw themselves as innovative using the four different class year groups (first year, second year, third year, fourth year and above). Post-hoc tests using Bonferroni's test were used to determine where the significant differences were found between groups.

The focus groups were transcribed by a professional service. The transcripts were labeled as either a first year focus group or upperclassmen focus group and the two categories were coded separately. Open coding was used to see what themes emerged within each category, and then the themes were compared across categories [31].

IV. RESULTS

A. Survey Results

To understand how student responses differed by class year, mean scores on each item on the survey were examined. This revealed that there are significant differences by class year in students' perceptions of several aspects of their innovative thinking skills. Bonferroni's follow-up tests allowed us to identify where there were significant differences between groups; in each analysis, the significant differences were between first year and fourth year students. Specifically, fourth year students indicated that they felt they were more adept at identifying and designing innovative solutions than first year students. Fourth year students also rated themselves higher in their ability to communicate innovative designs and solutions to faculty or industry representatives, and their ability to work with team members to design and share innovative solutions. The mean scores and standard deviation for each survey item are shown by class year in Table 1.

TABLE I. SURVEY RESULTS BY YEAR

Survey Items ($p \leq .05$) **Top = Mean** **Bottom = SD**	**In comparison to your peers, please rate yourself in the following areas:**			
	First Year (n=217)	***Second Year (n=128)***	***Third Year (n=111)***	***Fourth Year (n=148)***
Ability to identify innovative solutions*	3.70	3.78	3.94	4.02
	0.942	0.841	0.778	0.837
Ability to design innovative solutions*	3.60	3.70	3.92	3.89
	0.972	0.891	0.728	0.874
Ability to communicate innovative designs and solutions to others, such as faculty or industry representatives*	3.55	3.82	3.80	3.99
	1.067	0.934	0.769	1.027
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify and market innovative solutions).	3.70	3.95	3.78	3.91
	1.026	0.899	0.791	0.971
Ability to prototype innovative ideas and solutions*	3.38	3.62	3.69	3.62
	1.125	0.878	0.951	1.052
Ability to work with team members to design and share innovative solutions*	3.94	4.05	4.20	4.20
	0.936	0.822	0.784	0.896
Awareness of resources on campus that will allow me to participate in innovation activities	3.29	3.41	3.39	3.26
	1.061	1.046	0.983	1.127
Ability to use tools	3.50	3.63	3.67	3.55
	1.014	0.774	0.918	1.084
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions	3.65	3.74	3.81	3.83
	0.902	0.806	0.848	0.958
Ability to find unknown information and assess its value or worth.	3.64	3.73	3.86	3.75
	0.918	0.900	0.819	1.009

B. Focus Group Results

The transcripts of the first year and upperclassmen focus groups were analyzed separately first and then compared. Findings are similarly presented in this order of analysis.

1) First Year Focus Groups: First year students in our focus groups were relatively unified in their definition of the word "innovative." Nearly every group suggested the phrase "thinking outside the box," emphasizing the need for originality in innovative thinking. Participants agreed that innovation could involve either introducing a new idea or modifying an existing idea to improve it or adapt it for a different purpose. The first year students also regularly highlighted the fact that innovation involves iteration and that failures are an important part of the process. One student described it this way:

> *Honestly, that is probably the truest thing about engineering, is that when you start off, you have to go in expecting that it's not going to be perfect. Sometimes you'll have to go back to the drawing board even 30 times before you get something right. Honestly that's what I think is the most important part in innovative thinking.*

The first year focus groups were less likely to highlight the need for usefulness of an innovation, but several groups did mention this. Participants tended to describe this aspect of innovation as "meeting a need," describing situations where their own innovation stemmed from a problem they were facing. Some groups discussed the fact that innovation was more than creativity, with one student saying:

> *I think innovation is ... It is very special, because it's not just creativity. It's adding that application side to it, and you're not just designing this far-off thing that should be in a sci-fi movie. You're applying your creativity to the real world, it's not just pure creativity.*

At the same time, some participants found it challenging to even define "innovation." A few expressed the idea that as first year students, they had a limited understanding of the word. For example, one student said:

> *That's a hard question. I really don't know how to answer. [...] There's so many things I've already come across that I am not familiar with, so I think there's so many things out there that I don't understand that I just consider automatically to be innovative, even if I don't have that much background information. I think having such a limited perspective [...] it's hard for me to even come up with an answer for that question.*

One student referenced the fact that high schools do not encourage creativity, resulting in a lack of understanding of innovation. Other participants felt that engineering and innovation were nearly synonymous, and developing engineering knowledge would improve their understanding of innovation. One such student said

> *My definition for innovation and my definition for engineering are pretty much, exactly the same thing. Whenever you're an engineer you're problem solving, making things better. I want to do chemical, so it would be a process engineer to make a process move faster in a cheaper way like in innovation, that's what you do, too. You make something better for the benefit of others.*

Overall, the first year focus groups hit on many of the main concepts used in the literature to describe innovation, but lacked confidence about whether they had enough experience or knowledge to provide an accurate definition.

When asked about their own innovative thinking abilities, first year students were hesitant to claim that they had any. In each focus group, a few students agreed that they were innovative, while the majority said either "sort of" or "no" in a raising of hands. Those who did think of themselves as innovative argued that innovation can occur on a small "every day" scale. For example, one student said:

> *I think innovative just goes back to tinkering with things and changing them slightly. So if you're ... Something was like ... It was the basketball hoop. It kept falling over because there wasn't enough water. It's like thinking and using that problem-solving skills. Well, why don't I get that big rock over and it'll work, and it'll balance it out. But it's the creativity and problem-solving together. So it can stem from the little innovations when you're a kid, making new Legos or whatever to full-blown ... Here's this new cellphone. I think everyone can be innovative, in a way.*

On the other hand, some of the students less confident in their innovative thinking felt that their lack of engineering knowledge prohibited real innovation. Others stated that they would like to think of themselves as innovative, but had not had any opportunity to put it into practice, as described here:

> *I feel like I have the potential to be, but I've never had the chance to do something, especially related to engineering that is say, innovative. We're doing the project this semester ... Building the plane prototype to try to make it fly. I feel like, stuff like that, I could excel in making, but I've never had the chance to do that before. Now it's just ... We're just now starting it. I feel like I could, but I don't know if I am.*

These students seemed to think of innovation on a bigger scale, picturing major technological advances. However, regardless of whether or not participants thought of themselves as innovative, few of the first year students were able to provide examples of their own innovation. The most common examples came from creative areas, such as music, cooking, or art, but were relatively vague and nonspecific. Other student responses were entirely theoretical, discussing how they could be innovative in the future. Overall, the first year students tended to think of innovation as closely related to engineering, and thus struggled to see themselves as innovative.

2) Upperclassmen Focus Groups: The focus groups with upperclassmen revealed more nuanced ideas about what it means to be "innovative." Participants identified the need for originality, using similar terms to the first year students (e.g. "thinking outside the box" or "never been done before"). However the upperclassmen emphasized more heavily the need for practicality and usefulness in an innovative product. They highlighted that it was important to start with a problem that needs to be solved or a need that people have. Similarly, the upperclassmen felt that the final solution needed to be designed with customers in mind. This did not apply simply to what customers wanted in the product, but also the possible ethical issues and big picture impacts that the product might have. In describing the impacts of Uber, one upperclassmen stated:

> *The law follows technology. The law is behind technology, for instance. They found loopholes in the current taxicab law system, exploited the hell out of them. Sorry. Excuse my language. It does lead to bad effects though, too, so it depends on how ... You have to consider ethics when you're being creative, I guess is what I'm saying. How many people do you want to suffer, or how many people do you think might suffer from your innovation?*

Thus, the upperclassmen focus groups defined innovation similarly to the first year students, but in greater depth. However, they did not capture some of the innovation process concepts that the first year students identified (e.g. iteration and failure).

With regards to their own innovation skills, the upperclassmen were more likely to say they were innovative. Similar to the innovative first year students, they were able to see innovation happening outside of engineering. When asked for examples of their own innovative ideas, the upperclassmen discussed their extracurricular activities and hobbies such as art or music. For example,

> *I'm a cadet and so PT physical training ... like how we work out and stuff so every semester we have to take two PT tests. [...] I think that it really wasn't fair for everybody to have the same standard so I got with three other cadets and revamped it and made it more like a tier system. You fell into a range ... Based on your PT score performance, you only have to show up to if it's PT one, two, or three times a week and then you make up the extra days by doing workouts on your own.*

And similarly,

> *One thing in general is I do a lot of paintings. Sometimes I combine the watercolor and oil color together and that really makes something different.*

Thus, while the upperclassmen were more confident in their innovative thinking abilities, this seemed to be mainly tied to their experiences outside of the classroom. Upperclassmen identified extracurricular activities as their primary opportunities to exhibit innovative thinking.

3) Comparing First Year Students to Upperclassmen: The most notable difference between the first year and upperclassmen focus groups was their level of confidence in their own innovative thinking ability. This difference mirrors what was found in the survey results, while also providing some insight into the reasons for the difference. The focus groups revealed that while first year students and upperclassmen had similar definitions for innovation, the first year students more closely linked innovation with engineering. Due to their lack of engineering skills, they expressed less confident in their ability to be innovative. Greater engineering knowledge did not seem to be what increased the upperclassmen's confidence, however. In describing their innovative ability, the upperclassmen primarily discussed extracurricular activities. It appears that they are more willing to accept these as opportunities for innovation than the first year students.

Another difference between the first year focus groups and the upperclassmen groups was the number of unique ideas shared by the upperclassmen. The upperclassmen groups took significantly longer to discuss the same number of questions, because they tended to challenge their own and each other's ideas, bring up examples from classes or internships, and recognize that multiple perspectives could exist on the same topic. For example,

> Student 1: *One of the words that I like, that makes me think of what you just said, is disruption, or disruptive. Whenever I talk to someone outside the entrepreneurial community, or entrepreneurial mindset, they think it's a negative connotation…*
> Student 2: *That's interesting. I always thought of disruptive as being a negative word.*
> Student 3: *It depends on the effects of the disruption. If the disruption causes mass chaos, then it would not be good.*

Along the same lines, in the other focus group, the students asked each other multiple times "What do the two of you think?" and "What about you civil engineers?" inviting each other to add to the conversation. This difference in the conversation of the groups reveals some inherent innovative thinking in the upperclassmen. When faced with open-ended questions regarding the definition of innovation, the upperclassmen exhibited more divergent thinking and willingness to adjust their working definitions of innovation. Though they did not include iterative improvement in their definition of innovation, they did implement it in the course of their discussions.

V. Discussion

Both the survey and the focus groups revealed that upper class engineering students are more confident in their innovative thinking skills than first year students. The survey indicated that this confidence exists for a variety of activities, including identifying, designing, communicating, and prototyping innovative solutions. Fourth year students also indicated more confidence in their ability to contribute innovative solutions in team projects and in the workplace. The focus groups supported these conclusions and provided insight into why the upperclassmen are more confident in their innovative thinking. For example, the survey indicated that both third and fourth year students felt more confident than first year students in their "ability to design innovative solutions," with mean scores of 3.92 and 3.89 compared to 3.60 (Table 1). This was reflected in the focus groups, where first year students stated that they did not know if they were innovative and the upperclassmen were quicker to provide examples of their innovative solutions. The first year students perceived innovation to be highly related to engineering, and thus many felt that they lacked the technical knowledge to be truly innovative. The upperclassmen, on the other hand, did not connect innovation to engineering as closely. When asked for examples of their innovative thinking abilities, they emphasized hobbies and extracurricular activities. These combined results suggest that first year students might benefit from incorporation of hands-on activities into first year courses where they can explore their innovative thinking abilities. This may also help engineering students gain an engineering perspective on innovation that they can carry throughout their college careers.

These results are interesting in light of what previous studies have indicated. In particular, the fact that the upperclassmen emphasized the need for practicality in an innovative design supports earlier findings that they create more practical designs than first year students [24]–[26]. In terms of practicality, then, the first year students might be right that their lack of technical knowledge could hinder their ability to create an innovative design. On the flip side, however, the studies that look for both originality and practicality in student designs find the first year students to be more innovative [12], [23]. It appears that, although both sets of focus groups identified originality as a primary aspect of innovation, they may be weighting practicality more heavily in their assessments of their own skills. It is also possible that neither group has a clear idea of what originality really entails or are unable to assess their own levels of originality. It is concerning, however, that students may be leaving school believing themselves to have developed their innovation thinking skills when these skills may actually have declined.

One implication of this study is that engineering educators need to consider how we are teaching students to view the concept of innovation. Teaching can occur explicitly through the content covered in engineering courses, but it can also be implicit through how courses are taught and what is excluded from the content. This study suggests that students may come in associating innovation with engineering, but lose this association throughout their time in college. While it may be good for students to identify opportunities for innovation outside of engineering, it would be better if they could also identify opportunities within their classes. The fact that students recognized innovation primarily in their hobbies and extracurricular activities implies that the topic of innovation is not discussed sufficiently in engineering coursework and few opportunities are provided to be innovative. Educators wishing to avoid this result could consider being intentional in discussing innovation in their classes and providing opportunities for students to explore their innovative ability in ways that relate to engineering.

This study introduces several opportunities for future research. One area of interest would be to explore what kinds of extracurricular activities help students to build innovative thinking skills. Identifying these experiences would inform educators as they work to incorporate innovative thinking activities in their classrooms. Another question to consider is whether certain engineering disciplines are more encouraging of innovative thinking than others. A future study could explore the nature of projects and pedagogy in different engineering disciplines to see if relevant differences emerge. Finally, it is worth noting that the studies [12], [23] comparing innovation in first year and senior engineering students' designs use *engineering* design problems. This study suggests that the upperclassmen may not relate innovation to engineering, implying that they may compartmentalize their innovative thinking skills from their engineering design skills. To test this hypothesis, it would be interesting to try similar studies, but using non-engineering innovative activities.

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