International Journal of Engineering Education Vol. 35, No. 6(A), pp. 1642–1655, 2019
Printed in Great Britain

0949-149X/91 $3.00+0.00
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Learning Experiences that Facilitate Innovation and Workforce Preparation: Exploring the Impact of In-Class and Extracurricular Activities*

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The ability to think innovatively is necessary for important workforce outcomes and is linked to the production of successful entrepreneurial endeavors. Gaining a better understanding of in class activities and extracurricular experiences that facilitate development of innovative thinking plays a critical role in developing engineering graduates who can contribute innovative ideas and solutions in the workforce. A mixed-method study (N = 595 survey, N = 52 focus group) was undertaken to understand what classes, groups, activities, or other resources influenced students' innovative thinking. Our findings indicate that as engineering students progress through their undergraduate career they feel more prepared to contribute innovative solutions in future workplace settings. However, our study indicates that students do not engage in activities that facilitate development of innovative thinking skills until their fourth year of study. Educators would benefit from weaving opportunities throughout students' undergraduate experience including those that incorporate increased opportunities for students to share ideas, gain different perspectives, and solve problems in environments inside and outside of an engineering classroom.

Keywords: innovation; extracurricular activities; work force preparation; innovative thinking skills

1. Introduction

Improving the creativity and innovativeness of engineering students represents an important mandate for national competitiveness of and social well-being for the United States. Innovation is recognized as the single most important ingredient in any modern economy [1] and plays a role in developing human capital. The more adept employees are at generating solutions and considering new approaches and their applications, the more likely organizations will be successful [1, 2].

Despite the national need to secure human capital that will advance the economic state, few formal or informal educational curricula exist that actually teach students how to successfully innovate. A particular criticism of university education is that it inhibits student creativeness and innovativeness [3–5]. Students enter their engineering degree programs with creative inclinations, but often find their programs are too structured and prescribed. Students graduate discouraged and less likely to pursue creative endeavors [4, 5]. Structured assignments created in disciplinary silos tend to limit students' ability to address open-ended problems that require application of interdisciplinary knowledge; yet such problems are indicative of today's industry and societal challenges [6, 7].

Innovative thinking facilitates graduates' ability to function in complex work environments [8]. Innovative thinking skills are a fundamental building block for successful entrepreneurial activity [9–11]. In their *Innovation Education Continuum Framework* Duval-Couetil and Dyrenfurth [12] outline a clear link between innovation and creativity and suggest that innovation is an input to important outcomes such as entrepreneurship.

Although literature addresses the importance of developing innovative thinking skills, less is known about how experiences designed to promote innovative thinking can be included as part of the undergraduate experience to maximize career readiness. Our study focused on understanding how engineering undergraduates perceived their level of innovative thinking as it relates to work force preparedness and what classes, groups, activities, or other resources influenced their innovative thinking skills.

1.1 Innovation skills framework

The conceptual framework for this study is a model that presents innovation skills as a set of higher order thinking skills [13]. The model operationalizes innovation skills into three categories relevant to a learning environment: Knowledge, Skills, and Attitudes [13]. *Knowledge* is the ability to think and work with others by using techniques such as brainstorming and understanding how to imple-

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* Accepted 6 June 2019.

ment innovations. *Skills* include the abilities to communicate new ideas and design prototypes. *Attitudes* include openness to new ideas and the ability to provide and receive critical feedback on ideas [13].

Looking specifically at an engineering context in light of this model, several authors have identified competencies that innovative engineering undergraduates should possess [3, 14–16]. Engineering educators suggest that students should be able to set their own learning goals and be able to identify what gaps exist in their knowledge as they look to solve problems. Innovative thinkers should be able to provide others with feedback and consider how to use the feedback they receive. Engineering undergraduates should also have the ability to represent ideas in visual as well as contextual formats [3, 14–16]. Critical thinking skills are also important in determining the value of knowledge and synthesize existing content to address problem-based work [3, 15]. Students should also be able to consider the multiple factors that facilitate commercialization and prototyping [17].

1.2 Innovation skill development and pedagogical approaches

Prior studies have identified a variety of pedagogical approaches that help develop innovation skills. Innovation skills and competencies can be learned if individuals are provided with the opportunity to exercise these skills and practice the related thought processes. For instance, opportunities that allow students to see faculty or peers model new ways of approaching problems, having experiences that allow students to question common approaches, and promoting interactions with people who have different ideas can increase innovative thinking skills and generate more creative solutions [9]. Collaborative, hands-on learning strategies can promote active learning and develop innovative thinking among undergraduates [18–20]. Assignments that present theories, models, or content in unfamiliar contexts and promote peer-to-peer feedback also facilitate development of innovative thinking skills. For example, innovative thinking can be encouraged through ill-structured problem sets that can be solved in team-based environments where students can provide substantive feedback to one another [21–24]. Students should have the opportunity to clarify their own understanding and investigate other potential solutions. Asking questions to peers or mentors allows students to check their own understanding, reflect, and generate innovate thinking skills as they build on their prior content knowledge [25, 26].

In addition to these in-class experiences, extracurricular activities can also increase innovative thinking skills in undergraduate students. Studies have found that creativity among engineering undergraduates can be enhanced through repeated practice in extracurricular design activities [3]. Experiential learning opportunities where engineering students engage in real-world problem-based learning coupled with industrial visits demonstrate increased innovative thinking skills [27]. Similarly, applying the design and innovation process to community-based challenges positively impacts students' self-efficacy in innovation related tasks [28]. However, growth in innovative thinking skills can be restricted by design fixation, which leads engineers to follow previous models. Rather than presenting new alternatives, engineers replicate features found in models they are already familiar with in new models they propose [5]. Design fixation prevents engineers from considering new approaches or potentially better alternatives [5, 29] and has been cited as a reason that senior level engineering students do not demonstrate higher-level innovative thinking than first year engineering students [5].

Although there are practices that can encourage innovative thinking, little is known about the impact curricular and co-curricular experiences have on engineering undergraduates' ability to create innovative solutions and how that translates to workforce preparation. Our study was designed to address this gap. This project examined four research questions:

- How do undergraduate students' perceptions of their innovative thinking skills differ by year of study?
- How does students' reported frequency of engagement in innovation activities change over the course of their undergraduate career?
- Are different experiences inside and outside of the classroom related to students' perceived preparedness to contribute innovative ideas and solutions in the workplace?
- What experiences do students feel prepare them to engage in innovative thinking and provide innovative solutions in a workplace?

2. Methodology

To address the research questions above, a mixed methods approach was used. Mixed methods studies consider several data sources that can be used to understand a phenomenon from different perspectives. In this study, we first measured whether there were quantifiable differences in innovative thinking skills, then explored differences between student responses using a qualitative approach to better understand the survey responses. Using a sequential explanatory strategy, we used an online survey to explore differences in students' perceived innovative thinking skills by class year, the frequency with which they used innovative thinking skills, and whether they felt prepared to present and implement innovative solutions and ideas in the workplace (e.g., in industry or other employment). These concepts were investigated from a qualitative approach using focus groups to understand what factors students believed influenced their ability to design and contribute innovative solutions [30]. This paper presents the comprehensive findings from this study and analyzes differences across multiple class years to build on earlier reported findings [31].

2.1 Instrumentation

Items on the online survey asked participants to rate their ability to complete various innovative thinking activities in comparison with their peers on a five point Likert scale ranging from 1 = Well Below Average to 5 = Well Above Average. Students rated their experiences in (a) recognizing and creating innovative solutions, (b) describing innovative solutions to audiences, (c) using tools in innovative environments, (d) doing team-based work, and (e) synthesizing engineering concepts to explore problems.

Another set of questions asked students to indicate how frequently during a semester they engaged in different activities linked to innovative thinking. Prompts asked them to rate how often they: (a) identify innovative solutions, (b) design innovative solutions, (c) present and discuss innovative designs and solutions to different audiences, (d) work in team-based setting to generate innovative ideas, (e) use different tools, technologies, and resources on campus to prototype or design innovative ideas, (f) use engineering concepts in innovative ways, and (g) determine whether new information is needed when presented with a problem. Participants could select "Never/Not at all," "Not Often (once a month or less)," "Sometimes (about every other week)," or "Often (at least once every other week)."

One question provided participants with an opportunity to highlight activities they were engaged in that influenced their innovative thinking skills. The question had a list of activities on campus that included: living learning communities (i.e., on campus housing/residence halls) specific to engineers and one that emphasized innovation explicitly, entrepreneurship club, entrepreneurship minor, use of engineering student lab space, entrepreneurship classes, and study abroad experience. In addition, there were two spaces where students could indicate if there were other classes or activities that they felt helped them develop innovative thinking skills. Students could select all of these options that applied to them. To use these questions in the analysis, the responses were re-coded into the following groups by the research team: "Class with Innovative Thinking Outcomes," "Innovation Minor," "Engineering/Interdisciplinary Lab," "Living Learning Community," "Co-Op/Internship," "Club or Sports," and "Study Abroad." If students indicated participating in these activities they were coded as a participant if they had not participated they were coded as a non-participant.

One question served as the primary variable of interest for this study. Participants were asked to what extent they feel prepared to present and implement innovative solutions in the workplace (e.g., in an industry or other employment position). Respondents could select "Very Well Prepared," "Prepared," "Somewhat Prepared," or "Not Prepared at All."

In the context of sequential explanatory mixed method design the quantitative data leads the design of qualitative inquiry [30]. We developed a focus group interview protocol to use with the engineering undergraduates after the survey data was analyzed. Protocol questions asked participants to discuss how they define innovative thinking and what experiences inside and outside of the classroom allowed them to exercise innovative thinking skills.

2.2 Data collection

In the 2016 spring semester 7,402 engineering undergraduates were emailed an invitation to participate in an online survey. This initial invitation was followed by a reminder one week later to non-respondents. The final sample used for this study included 595 students who provided complete responses to the survey.

In the second stage of the study, focus groups were held to better understand which experiences students felt prepared them to engage in innovative thinking and would allow them to provide innovative solutions in a workplace. Invitations to participate in the focus groups were sent separately to first-year and upper class students via email. Participants were offered a small meal as a means to incentivize participation and each focus group lasted one hour. 43 first year students participated in five focus groups and nine upper class students participated in two focus groups. A professional service was used for transcription. The transcripts were identified as either being generated by the first-year students or by the upperclassmen and then coded separately.

2.3 Reliability and validity

To establish the reliability and validity of the survey several steps were taken [32]. A group of practitioners in the field and faculty in engineering education reviewed a draft of the survey items as an initial step to establish construct validity [33]. After incorporating their feedback, a pilot survey was conducted in spring of 2015. For both groupings of questions that used a Likert scale (measuring innovative thinking skills and frequency of use of innovative thinking skills) factor analysis was conducted and internal consistency analyses were performed using Chronbach's alpha. The factor analysis demonstrated a one factor structure and factor loadings that exceeded 0.60. The Chronbach alpha scores ranged from 0.84 to 0.87 indicating that there was a high internal consistency among the items [31]. To establish the reliability of the survey [33] this analysis was repeated on responses and similar scores were received on the items ranging from 0.86 to 0.87 [31].

2.4 Data analysis

For the survey data, ANOVA analyses allowed for an initial exploration of differences by class year in students' perceived ability to contribute innovative solutions in the workplace, overall ability in innovative thinking skills, frequency of engagement in innovative activities, and engagement in specific innovation-based activities. The next step in the data analysis used a four-stage hierarchical multiple regression to examine whether these factors along with class standing and GPA predicted student preparation to contribute innovative solutions and ideas in the workplace. Hierarchical multiple regression permits for the specification of the order in which variables are entered. This procedure controls for the interaction of other variables and can test the effects of variables independent of the influence of others. For our analysis, perceived preparation to offer innovative solutions in the workforce served as the dependent variable. In stage one, measures of students' innovative thinking skills were entered into the model. In state two, items that asked students how often they engaged in innovative thinking activities were entered. In stage three, students' class year and GPA were entered. In stage four, academic and curricular activities that were identified as contributing to innovative thinking were entered into the model.

With regard to the qualitative data, focus groups were conducted to better understand the responses students provided in the survey and explore in more detail the in-class and out of classroom experiences they felt had encouraged or discouraged their preparedness to present innovative solutions in the workplace. Open coding of the focus group transcripts allowed the research team to see what themes emerged. Transcripts from the first-year groups and upper class groups were coded separately and then compared to identify similarities and differences in students' experiences [34]. In analyzing the transcripts intercoder reliability was established among the research team through regular meetings. When a final set of codes were established the research team engaged in a debriefing session with peers to discuss major themes that emerged and evidence supporting those findings [30].

3. Results

Our quantitative findings highlight differences by class standing in student perceptions of their innovative thinking and ability to provide innovative solutions in the workplace. The qualitative findings from the focus groups describe in the students' own words the experiences inside and outside of the classroom that they perceive to help their development of innovative thinking skills. Our findings support and further describe results reported in related studies [31].

3.1 Quantitative results

To answer the first research question (whether undergraduate students' perceptions of their innovative thinking skills differ by year of study), a comparison by class year was conducted to determine whether there were differences in students' perceived preparation to contribute to solutions in the workforce. As described in Table 1, results from an ANOVA indicate significant differences by class standing in student perceptions ($p < 0.001$).

There were also significant differences by class year in students' perceptions of innovative thinking skills and the frequency in which they engage in innovative thinking activities. Post-hoc tests allowed us to determine that the significant differences were between fourth year and first year students. There were three areas that fourth year students rated themselves higher than first year peers: (a) their ability to identify and design innovative solutions, (b) their communication skills

Table 1. Differences by Class Standing in Preparedness to Contribute Innovative Solutions (N = 595)

	First Year (n = 217)	**Second Year (n = 128)**	**Third Year (n = 111)**	**Fourth Year (n = 148)**
Extent to which they felt prepared to contribute innovative solutions in the workforce	2.56	2.59	2.79	3.02

Table 2. Confidence in Innovation Skills in Comparison to Peers by Class Year (N = 595)

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
Ability to design innovative solutions*	3.60	3.70	3.92	3.89
Ability to communicate innovative designs and solutions to others, including faculty or industry representatives*	3.55	3.82	3.80	3.99
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them).	3.70	3.95	3.78	3.91
Ability to prototype innovative ideas and solutions*	3.38	3.62	3.69	3.62
Ability to work with team members to design and share innovative solutions*	3.94	4.05	4.20	4.20
Awareness of resources on campus that will allow me to participate in innovation activities	3.29	3.41	3.39	3.26
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions	3.65	3.74	3.81	3.83
Ability to find unknown information and assess its value or worth	3.64	3.73	3.86	3.75

Note: * Indicates significant differences between first year and fourth year at the $p \leq 0.05$ level.

related to innovative ideas, (c) their ability to generate innovative solutions in team-based environments (refer to Table 2).

ANOVA results on the frequency of engagement in different innovation activities revealed significant differences between first-year and fourth year students on the frequency with which they identify innovative solutions. This was the only variable where there were significant differences by class standing (refer to Table 3).

Finally, we examined whether students were more likely to participate in different activities by class year. Respondents to our survey appear to participate in-class and out-of-class activities that were identified as contributing to innovation at the same rate regardless of class year (refer to Table 4).

The third research question in this study focused on factors that might predict the variation in students' perceived ability to contribute to innovative solutions in the workforce. The hierarchical multiple regression revealed that at during step one, students' perceived ability to engage in innovative thinking, use hands-on tools, and apply or integrate content knowledge when offering innova-

Table 3. Frequency of Engagement in Innovation Activities by Class Year (N = 595)

How often during a typical semester do you engage in the following:	**First Year (n = 217)**	**Second Year (n = 128)**	**Third Year (n = 111)**	**Fourth Year (n = 148)**
Identify innovative solutions*	1.32	1.61	1.40	1.41
Design innovative solutions.	1.24	1.41	1.33	1.45
Communicate innovative designs and solutions to others, including faculty or industry representatives.	1.54	1.42	1.38	1.49
Prototype innovative ideas and solutions.	1.41	1.65	1.59	1.63
Work with team members to design and share innovative solutions	1.62	1.41	1.49	1.58
Use resources on campus to participate in innovation activities	1.65	1.56	1.82	1.84
Use different technologies in the innovation process	1.42	1.54	1.44	1.51
Apply or integrate engineering content knowledge to generate new ideas or solutions	1.38	1.55	1.36	1.48
Find unknown information and assess its value or worth	1.50	1.48	1.54	1.43

Note: * Indicates significant differences between first year and fourth year at the $p \leq 0.01$ level.

Table 4. Participation in Innovation Activities by Class Year (N = 595)

	First Year (n = 217)	**Second Year (n = 128)**	**Third Year (n = 111)**	**Fourth Year (n = 148)**
Class with Innovative Thinking Outcomes	104	57	65	74
Innovation Minor	20	12	15	25
Interdisciplinary Lab	63	45	50	58
Living Learning Community	45	32	17	26
Co-op/Internship	2	5	2	7
Club or Sports	19	11	10	5

Table 5. Summary of Hierarchical Regression Analysis for Variables Predicting Workforce Preparation—Step 1

Variable	*β*	***T***	***p***	***R***	***R2***	**∆*R2***
Step 1				*0.485*	*0.235*	*0.235*
Ability to identify innovative solutions	0.066	1.205	0.229			
Ability to design innovative solutions*	0.183	3.118	0.002			
Ability to communicate innovative designs and solutions to others, including faculty or industry representatives*	0.115	2.390	0.017			
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them)	–0.080	–1.752	0.080			
Ability to prototype innovative ideas and solutions	0.065	1.352	0.177			
Ability to work with team members to design and share innovative solutions	–0.043	–0.973	0.331			
Awareness of resources on campus that will allow me to participate in innovation activities	0.045	1.034	0.301			
Ability to use different tools*	0.119	2.315	0.021			
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions*	0.155	2.821	0.005			
Ability to find unknown information and assess its value or worth	–0.049	–1.068	0.286			

Note: * Indicates significant contribution to model at the $p \leq 0.05$ level.

tive solutions contributed significantly ($p < 0.001$) to the model, F (584, 594) = 17.920 and accounted for 23.5% of the variation in students' reported ability to contribute innovative solutions in the workforce (refer to Table 5).

Introducing the frequency that students engaged in innovative thinking skills explained an additional 2.3% of variance and contributed significantly to the model F (575, 594) = 2.015, p = 0.036. The additional variable that accounted for a significant portion of the increase included the frequency during a typical semester in which students' prototyped innovative ideas and solutions (refer to Table 6).

Table 6. Summary of Hierarchical Regression Analysis for Variables Predicting Workforce Preparation—Step 2

Variable	*β*	***T***	***Sr2***	***R***	***R2***	**∆*R2***
Step 2				*0.508*	*0.258*	*0.023*
Ability to identify innovative solutions	0.075	1.353	0.177			
Ability to design innovative solutions*	0.166	2.845	0.005			
Ability to communicate innovative designs and solutions to others, including faculty or industry representatives	0.116	2.407	0.016			
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them).	–0.080	–1.736	0.083			
Ability to prototype innovative ideas and solutions.	0.047	0.959	0.338			
Ability to work with team members to design and share innovative solutions.	–0.031	–0.701	0.484			
Awareness of resources on campus that will allow me to participate in innovation activities	0.033	0.730	0.466			
Ability to use different tools*	0.121	2.331	0.020			
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions *	0.149	2.689	0.007			
Ability to find unknown information and assess its value or worth.	–0.045	–0.973	0.331			
Identify innovative solutions	0.019	0.405	0.686			
Design innovative solutions.	0.009	0.204	0.839			
Communicate innovative designs and solutions to others, including faculty or industry representatives.	–0.036	–0.792	0.429			
Prototype innovative ideas and solutions.*	–0.124	–2.569	0.010			
Work with team members to design and share innovative solutions	0.020	0.454	0.650			
Use resources on campus to participate in innovation activities	–0.024	–0.528	0.598			
Use different technologies in the innovation process	–0.025	–0.517	0.605			
Apply or integrate engineering content knowledge to generate new ideas or solutions	0.044	0.938	0.349			
Find unknown information and assess its value or worth	0.009	0.210	0.834			

Note: * Indicates significant contribution to model at the $p \leq 0.05$ level.

Table 7. Summary of Hierarchical Regression Analysis for Variables Predicting Workforce Preparation—Step 3

Variable	β	T	p	R	R2	ΔR2
Step 3				*0.538*	*0.289*	*0.263*
Ability to identify innovative solutions	0.060	1.100	0.272			
Ability to design innovative solutions*	0.158	2.753	0.006			
Ability to communicate innovative designs and solutions to others, including faculty or industry representatives	0.088	1.854	0.064			
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them)	–0.072	–1.589	0.113			
Ability to prototype innovative ideas and solutions	0.039	0.805	0.421			
Ability to work with team members to design and share innovative solutions	–0.046	–1.062	0.288			
Awareness of resources on campus that will allow me to participate in innovation activities	0.047	1.061	0.289			
Ability to use different tools*	0.139	2.725	0.007			
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions*	0.151	2.771	0.006			
Ability to find unknown information and assess its value or worth.	–0.046	–1.008	0.314			
Identify innovative solutions	0.015	0.338	0.736			
Design innovative solutions	–0.002	–0.040	0.968			
Communicate innovative designs and solutions to others, including faculty or industry representatives	–0.019	–0.434	0.665			
Prototype innovative ideas and solutions*	–0.137	–2.888	0.004			
Work with team members to design and share innovative solutions	0.024	0.553	0.581			
Use resources on campus to participate in innovation activities	–0.030	–0.672	0.502			
Use different technologies in the innovation process	–0.023	–0.493	0.622			
Apply or integrate engineering content knowledge to generate new ideas or solutions	0.031	0.677	0.499			
Find unknown information and assess its value or worth	0.021	0.509	0.611			
Grade Point Average	0.036	1.002	0.317			
Academic Level/Class Year*	0.178	4.859	0.000			

Entering students' class year and GPA in step three accounted for an additional 3.1% of the variance and contributed significantly to the model, F (573, 594) = 11.117, $p < 0.001$. In the third model the additional variable that accounted for a significant amount of the variance included student class year or academic standing (refer to Table 7).

Step four of the model introduced specific activities that students were engaged in that were linked to innovation. This accounted for 1.0% of the variance and did not contribute significantly to the model (refer to Table 8).

3.2 Qualitative results

Three main themes emerged from the focus groups that helped us better understand what experiences students felt prepared them to engage in innovative thinking and provide innovative solutions in a workplace. The first theme was that both first-year students and upperclassmen looked for opportunities to experience different perspectives. The second theme focused on participation in extracurricular activities that provide hands-on activities in non-threatening, non-judgmental environments. The third theme was related to in-class activities that provided opportunities to exercise innovative thinking skills through problem-based learning. These themes are summarized in Table 9 and will be described in more detail in the following sections.

Experiencing Different Perspectives. Students indicated that interactions allowing them to see different perspectives through discussion, instructor and peer modeling, or critical feedback provided opportunities to develop innovative thinking skills. For example, a first-year participant explained how group work helped them see different viewpoints:

> "I think in college we work with a lot of groups and there are often times where you have to do a manager's review or your teacher will grade your assignment, so you get a lot of feedback and from that . . . you can understand what you might have done wrong and how you can do it better and so, that encourages you to think innovatively by coming up with ways you can do something different to change the outcome."

Upperclassmen also cited the value of experiences that allowed for different ideas to be shared as important for development of innovative thinking. One participant explained, "Being able to bounce ideas off of people because it's somewhat harder I

Table 8. Summary of Hierarchical Regression Analysis for Variables Predicting Workforce Preparation—Step 4

Variable	β	***T***	***Sr2***	***R***	***R2***	Δ***R2***
Step 4				*0.547*	*0.299*	*0.010*
Ability to identify innovative solutions	0.065	1.175	0.240			
Ability to design innovative solutions*	0.156	2.706	0.007			
Ability to communicate innovative designs and solutions to others, including faculty or industry representatives	0.085	1.784	0.075			
Motivation to develop innovative thinking skills (e.g., skills that will allow me to identify innovative solutions and market them).	–0.063	–1.373	0.170			
Ability to prototype innovative ideas and solutions.	0.045	0.935	0.350			
Ability to work with team members to design and share innovative solutions.	–0.045	–1.032	0.302			
Awareness of resources on campus that will allow me to participate in innovation activities	0.041	0.934	0.350			
Ability to use different tools*	0.139	2.728	0.007			
Ability to apply or integrate engineering content knowledge to generate new ideas or solutions *	0.151	2.781	0.006			
Ability to find unknown information and assess its value or worth.	–0.049	–1.077	0.282			
Identify innovative solutions	0.013	0.287	0.774			
Design innovative solutions.	–0.006	–0.127	0.899			
Communicate innovative designs and solutions to others, including faculty or industry representatives.	–0.026	–0.579	0.563			
Prototype innovative ideas and solutions.*	–0.137	–2.866	0.004			
Work with team members to design and share innovative solutions	0.025	0.579	0.563			
Use resources on campus to participate in innovation activities	–0.023	–0.502	0.616			
Use different technologies in the innovation process	–0.015	–0.314	0.754			
Apply or integrate engineering content knowledge to generate new ideas or solutions	0.031	0.681	0.496			
Find unknown information and assess its value or worth	0.018	0.437	0.663			
GPA	0.063	0.996	0.320			
Academic Level/Class Year	0.120	4.786	0.000			
Class with Innovative Thinking Outcomes	–0.135	–2.006	0.045			
Innovation Minor	0.112	1.147	0.252			
Interdisciplinary Lab	0.006	0.101	0.919			
Living Learning Community	0.074	0.991	0.322			
Co-op/Internship	0.222	1.164	0.245			
Club or Sports	0.168	1.402	0.161			

Note: * Indicates significant contribution to model at the $p \leq 0.05$ level.

feel like to be innovative . . . I feel like if you're individually working on something, you get stuck on one idea." Another senior-level student explained how different perspectives allow for deeper thought, "[Working alone] . . . the first idea you think of is, 'Yeah, that's good, that's fine. We'll just do that.' You don't have somebody else to be like, 'Oh well, let's keep thinking of other stuff.'" Different perspectives were seen as critical in generating creative ideas and solutions as one upperclassman noted, "To innovate, you need to be creative . . . I think we could do well to include more artists in our innovation process."

A first-year student explained how in-class experiences such as modeling different problem-solving methods can positively impact innovation skill development and preparedness:

> "If my math teacher said, 'Do this problem,' and then we do the problem and he explains it. The way I did it is typically different than the way my peers did it and the way he's going to explain it is much different than all of it. I think that . . . That also helps teach innovation even on a little scale inside a classroom because you see the difference between thinking about it in different ways and how some of them can be much better than others if you just take the time to think about it before you start."

Assignments that encouraged students to interact with people that might have different views was important. One student explained how this occurred through their engineering seminar:

> "Definitely my engineering seminar . . . I saw that as being a helpful thing because of the activities that we're required to do. Social events, professional development, outreach services. I've seen that as definitely

Table 9. Summary of Key Experiences That Prepare Students to Provide Innovative Solutions in Future Workplace Settings

Key Themes	Experiences Among First-Year Students	Experiences Among Upperclassmen
Experience different perspectives	Class discussions, critical feedback from peers, instructor modeling	Study abroad, class discussions that encouraged sharing different views
Participation in hands-on, non-graded extracurricular activities	Living learning communities, design teams even in an observing role	Design teams, internships
In-class activities using problem-based learning	Speculated that future classes would provide problem-based opportunities	Classes that use problem-based learning activities

helping me to broaden my view and actually explore a broader perspective."

One student cited an interdisciplinary class that had a positive impact on their ability to provide innovative solutions because the class introduced them to how different disciplines view historical events.

Participants who had studied abroad highlighted this as an experience that changed their way of thinking about things because they were immersed in a culture that had different perspectives on life. As one participant explained:

"I want to say I value that study abroad semester more than I value most of the rest of my education here . . . because it gives me a broader outlook on culture and life, so you can take more people's ideas into account when you're trying to create something."

Overall, this first theme suggests that gaining different perspectives is important to both first-year students and upperclassmen in their perceived development of innovative thinking skills. The two groups differed somewhat in where they believed such perspectives came from (i.e., classmates vs. other disciplines or cultures), which reflected the broader types of experiences that upperclassmen had participated in at the time of the focus group.

Extracurricular and Out of Classroom Activities. With regard to hands-on experiences, both first-year students and upperclassmen cited the importance of extracurricular opportunities that allowed them to express and challenge new ideas without being graded. Students cited engineering-based living learning communities and design teams as providing this type of experience. Upperclassmen also cited the important role internships and co-ops played in allowing them to develop confidence in creating innovative solutions in the workplace.

First-year students indicated that participating in living learning communities that provide access to tools and opportunities to discuss different ideas makes them feel ready to contribute innovative solutions in the workplace. One first year student explained, "I think the [living learning community] space is really good about encouraging innovation because just having a 3D printer [in your residence hall], it encourages you to say, 'Hey, I can make something and I can print it out'."

First-year students who had access to this type of equipment in their residence halls explained that it also facilitated their innovation skills because they could discuss their ideas with other people who were using the design studio:

"The studio in [Residence Hall] is pretty good space, because it is a space where you can see people and talk with them and think about what you want. And then there's someone who's had a little more experience than you and maybe knows some more things that are going on, that you can ask questions or run your ideas by. And then there's plenty of equipment, and they have their idea book of all the other things that other people have done and they've turned out really cool. So that's something for you to start with if you don't have your own idea, or maybe something you want to contribute to if you do have ideas."

In addition to the hands-on experiences in their living learning communities, another out of classroom activity that first-year and upperclassmen cited as improving their ability to provide innovative solutions included participation in extracurricular design projects or teams. First-year students reported that they felt their undergraduate experience would prepare them well if they took advantage of the opportunities available to them. One student noted:

"There's also two dozen design teams, at least . . . They're like, senior design teams . . . They accept freshman. [name of team], most of the people that are really contributing are the seniors and the juniors that have been in aerospace and selective majors for a while. The freshman are still very welcome and throw out ideas and sometimes they're used. You can still be getting experience . . . Figuring stuff out even if you're not already in that level of class."

First-year students that had taken advantage of the extracurricular design teams felt that students could develop innovative thinking skills despite not having all of the content knowledge needed for advanced solutions. One participant explained:

". . . design teams that are led by seniors you're kind of just thrown in and . . . It's a crash course, honestly, . . . with design teams, you can just get the concepts thrown at you and hastily explained and then try to apply them. It is important to have the class-based . . . I think when done together . . . it helps overall."

Upperclassmen shared examples of extracurricular activities such as clubs that they participated in that helped them feel prepared to provide innovative solutions. One senior student explained:

> "I was for a couple of months in the Mobile App Development Club and basically it's just like some random club that some students formed. They just did it to make mobile Apps and get people together to make mobile Apps... Most of the time we spent just brainstorming. . . What would be cool? What would be used by people?"

The hands-on experiences in the living learning communities, design teams, and extracurricular clubs were valued because across class years students emphasized that they were not being graded or judged. Having the ability to think freely without being concerned about whether they were meeting specific criteria helped the students feel that the experiences would ultimately prepare them to contribute innovative solutions in the workplace. For example, one first year student explained how they experienced this during participation in a design team:

> ". . . That's why those little design challenges are so much more fun because it's . . . You're not going to get graded on how well [you do] . . . It's not something you're really worried about. Things you just design for yourself. . .You can put so much more effort and stuff into them is because you're not worried about what anyone else is going to think about it."

Upperclassmen participants echoed these same ideas. One senior level student explained that the ability to pursue new ideas in a non-threatening environment was important, "I feel like the freedom to do what you want". I mean, with the [design team experience] you say like, "Make any mixture, make any design, go for it. You use your knowledge to make something . . . It just that freedom to kind of let your mind wonder and do something interesting."

One benefit that students highlighted from the hands-on activities was that they provided opportunities for failure, allowing them to improve their creativity and ultimately preparing them to contribute innovative solutions in the workplace. One first year student explained:

> ". . . failures lead to more knowledge . . . you learn as a result of them like, what didn't work, what did. If you have a code essentially, and you run it, and there's an error in it, you've got to figure out where that error and why it's causing it. As long as you're continually trying to get it and you're adapting based on your results in which you got your failure, then I think your failures can do just as much as your successes."

One extracurricular experience that was cited by the upperclassmen participants only was the importance of internships and co-ops. As one participant explained:

> "I worked in Phoenix for [name of company], and they had this project that they assigned me to basically just changing a whole process of how they got customer approval for something. They had no ideas of how to change it, so I was kind of forced into coming up with an idea."

In some instances, the internships exposed them to interdisciplinary work that they thought was critical to developing innovative thinking skills.

First year and upperclassmen engineers noted that extracurricular activities that had a hands-on element improved their confidence in being able to provide innovative solutions in the workplace. Being able to express themselves and take risks without working solely for a grade were important components of these extracurricular experiences that helped them develop innovative thinking skills.

Classroom-Based Activities. A final theme that emerged was the role of classes in developing innovative thinking. Upperclassmen explained class activities that were structured to encourage problem solving made them feel more confident about their innovative thinking skills. First-year students could only speculate about how future classes would allow them to feel prepared, but many cited disciplinary knowledge as necessary for innovative thinking.

Upperclassmen explained that the senior design projects provide an extended period of time to really immerse themselves in a problem solving experience. One participant explained how this made them feel more innovative:

> "Our senior design class makes you be really innovative, especially because it's a year-long, so you have a lot of time to generate solutions . . . It takes everything you've learned in school and it's like, wow, I actually have to use this in the real world now, with a real company, and that's cool."

Computer science (CS) majors felt that their disciplinary courses really encouraged them to be innovative thinkers and prepared them well to contribute innovative solutions in the future due to the open-ended nature of assignments and ability to collaborate with peers on solutions. This experience contrasts with coursework described by other majors. For example, civil engineers who participated in the study noted that as they progressed in their program they were presented with problems that only had one answer and this made them feel less innovative.

First-year focus group participants noted that since starting their college career the general engineering classes that they were taking were the first time they had the opportunity to engage in activities in classroom setting that might encourage innovative thinking. One first year participant explained:

> "I feel like I have the potential to be [innovative], 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 . . . ."

First-year students felt that over the course of their undergraduate experience they would learn to be innovative by gaining disciplinary knowledge through class activities. One participant explained:

> "We don't know a whole lot about it [engineering], but that's why we came here, so that we can learn about it. When we have the skills and the tools and the knowledge to learn how to make solutions, that's when we're able to innovate and create the solutions to the problems that people are asking."

Findings from the focus groups also helped explain why first-year students may have rated themselves not prepared or only minimally prepared to contribute innovative solutions in the workplace on the survey. Some first-year students explained that there were a lack of opportunities to develop creative solutions in first year courses as described by this student:

> "I think college does a good job of teaching you how to not recreate the wheel. It gives you framework to do things that haven't been done before, but I think sometimes, there isn't enough in college that teaches you how to use what you already know and to apply it to something different."

Other first year students agreed that this may be due to the way classes were structured, "I feel like college hasn't really stressed the application of what we're learning. We may learn knowledge wise how to do something, but without having that actual hands on experience and applying what we've learned."

First year students speculated that their senior capstone course that includes problem-based group design project would help them become prepared to provide innovative solutions in the workplace.

Students' perspectives on how in-class activities would prepare them to provide innovative solutions in the workplace were influenced by the number and types of classes they had completed; however, across class years students felt it was important to have problem-based learning experiences. These types of experiences allowed the students to apply knowledge in new and different ways, ultimately making them more confident in their ability to offer innovative solutions.

4. Discussion

Our findings indicate that as engineering students progress through their undergraduate career they feel more prepared to contribute innovative solutions in future workplace settings. While several variables were examined to explore what may contribute to this confidence a few stood out. Across undergraduate students their perceived ability to engage in innovative thinking along with the opportunity to use hands-on tools and apply or integrate content knowledge when offering innovative solutions made students feel they were better prepared to contribute innovative solutions as they moved into their careers. Opportunity to prototype solutions was also important and our findings suggest that students may find this activity daunting and frustrating, making them feel less prepared to enter the workforce if they do not fully understand that failure or lack of success with the prototype can be a helpful learning experience. Additionally our findings underscore that students in their fourth year of study or above indicated on the survey that they were more likely to engage in activities that are linked to development of innovative thinking skills. Specifically, upperclassmen students indicated that they were more likely to engage in identifying innovative solutions during a typical academic semester. Senior level students also indicated that they were more capable than their peers in identifying and designing innovative solutions as well as communicating innovative designs and solutions to other audiences. Upperclassmen also reported that they felt more confident in their ability to prototype innovative ideas and solutions and work with team members to design and share innovative solutions. From our focus groups, most participants were more likely to cite involvement in extracurricular activities as a means by which they would be prepared to provide innovative solutions in the workplace. It appears that senior level students gain this sense of preparation from having multiple opportunities to engage in activities such as design teams and internships. These experiences are coupled with senior capstone projects that provide open-ended problem solving opportunities. Having several opportunities to apply knowledge to new contexts, create innovative solutions, and experience different perspectives seemed to facilitate their confidence in their ability to provide innovative solutions in the workplace.

Our findings suggest that it is important to provide students with open-ended, hands-on activities like senior level capstone design experiences and extracurricular design projects to prepare them to offer innovative solutions to the workplace. Faculty and administrators who develop and implement curricula may want to take the model used at the senior level and consider how it can be executed appropriately in first-year, sophomore and junior level courses. Having opportunities to engage in hands-on activities where students share ideas and get feedback in a non-graded environment were highlighted as important in the context of innovation skill development. Providing such opportunities consistently throughout the college experience may better prepare students to contribute innovative solutions in internships, co-ops, and throughout their career.

The findings from this study also indicate that faculty and administrators may want to think about how co-ops and internships are made available to engineering students enrolled in their programs. Students cited these experiences as an important contributor to their preparedness to develop innovative solutions in the workplace. These experiences provided opportunities to talk with working professionals and see how they used content knowledge to solve problems, often in an interdisciplinary setting. Demands of an engineering curriculum often deter students from engaging in these experiences and institutions may want to consider alternative ways students might be able to garner these same insights from experiences that do not require a semester long commitment.

Although the quantitative analysis did not yield significant findings with regard to extracurricular activities that prepare students to provide innovative solutions, the focus groups yielded insights to experiences that can help undergraduates exercise and develop these skills. Students at all levels indicated that having an opportunity to engage in open-ended activities in a non-judgmental context was important. They explained that discussing their ideas with peers, especially with supportive upperclassmen who may be more knowledgeable, built their confidence and allowed them to exercise innovative thinking skills without being graded on their performance. Faculty and administrators may want to consider ways to create such environments within their curriculum and in extracurricular experiences. Design competitions are commonly held on college campuses but universities may want to take a closer look at whether students across class years participate in these events. Another consideration is giving students access to design labs such as the one students in our focus groups mentioned. These first year engineering students have access to a studio equipped with a 3D printer in their residence hall. This resource is coupled with knowledgeable staff and an 'idea book' that allows students to brainstorm unique and innovative uses of the resources provided. Other universities may want to make these types of additions to residence halls or living learning communities that are populated with engineering students.

Past research has suggested that innovation and the ability to think creatively to develop innovative solutions is a fundamental for entrepreneurial outcomes and there should be increased opportunities for students to engage in entrepreneurship through curricular revisions [14]. Our study suggests that engineering educators may want to look just as closely at identifying how innovation and innovative thinking is developed, given its link to entrepreneurship and successful entrepreneurial outcomes. Findings from our study highlight important characteristics of experiences that develop innovative thinking that can be woven into the engineering curriculum so that there are more opportunities to prepare students to contribute innovative solutions in the workplace, including those that positively influence entrepreneurship.

The findings of this study were limited by the fact that we only looked at changes of students over the course of four years. It may be that more time and more experiences after college are needed to see noticeable changes in students' innovative thinking. Another limitation of this study was that it only sampled students at one university. Engineering programs structure their course content and requirements for experiences such as co-ops and internships very differently. Given this limitation, before faculty and administrators implement changes based on the findings from this study they may want to use this survey with their student population and compare their findings to the ones highlighted in this paper. Doing so may provide unique insights to the manner in which curriculum is structured and extracurricular experiences are made available to students at different institutions. Future researchers may want to compare engineering students with students from other disciplines to see whether engineers experience a unique sense of preparedness to provide innovative solutions. Findings from a study such as this could contribute to an understanding of how to structure interdisciplinary environments to facilitate a valuable exchange of ideas.

5. Conclusion

In conclusion, results from this study indicate that students feel more prepared to offer innovative solutions in the workplace as they reach their last year of undergraduate enrollment. Students perceive that they gain these skills from problem-based in class activities, through direct engagement with peers and faculty that allow them to be exposed to different ways of thinking, use of hands-on design tools, and from extracurricular activities such as study abroad, internships, and design team participation. Although these themes were consistent across both first-year and upperclassmen students, there was some variation in the examples provided by students in the different groups. These differences were primarily based on the wider variety of experiences the upperclassmen had participated in, leaving the first-year students to speculate in some cases about what they believed would occur in future classwork. Faculty and administrators can use the results highlighted to incorporate increased opportunities for students to share ideas, gain different perspectives, and solve problems in environments inside and outside of a standard engineering classroom. Increased opportunities will better prepare students to enter the workforce with innovation skills and engage in work place settings that are grappling with complex problems.

Acknowledgements—This work was supported by the Alfred P. Sloan Foundation under Grant # G-2013-5-09 SLS. This research was partially supported by the Alfred P. Sloan Foundation.

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