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Educating Engineering Entrepreneurs: A Multi-Institution Analysis*

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Engineering entrepreneurship demands a broad range of skills and knowledge, extending far beyond technical expertise in an engineering domain. Motivation and proactive behavior, professional skills (*e.g.*, communication, leadership, business), and creativity in problem solving are among the attributes linked with successful entrepreneurship. An extension of the Center for the Advancement of Engineering Education's Academic Pathways Study, this survey- and interview-based study of engineering undergraduates examines the potential of extracurricular activities to help students develop these entrepreneurial attributes. Quantitative analyses show positive relationships between entrepreneurial attributes and involvement in engineering and non-engineering extracurricular activities. Preliminary interview analyses illustrate how these activities foster entrepreneurial attributes and contribute to students' engineering education experiences, in general.

Keywords: entrepreneurship; undergraduate engineering education; extracurricular activities

1. Introduction

An oft-heard parable in the Silicon Valley tells of the roles and skills desired for a start-up team. The Chief Executive Officer should be able to share a vision of the entrepreneurial endeavor, network among peers in industry, and connect with an array of venture capitalists and other sources for potential funding. The Chief Technical Officer supports these activities by speaking the specific *lingua franca* surrounding the technology. The Vice President of Engineering should be the one actually able to do the engineering work. In short, the most pertinent roles for those engaged in entrepreneurship are to have motivation and be evangelical about it, to leverage professional and networking skills to build and drive a team, and to be able to work flexibly and creatively to tackle problems, small and large. The importance of these professional skills to bring together a powerful team cannot be underestimated.

A novel artifact or service is often the outcome of entrepreneurial activities, whether in social entrepreneurship, where social good is at least as important as fiscal viability, or in business. Engineers Without Borders, microfinancing organizations like Grameen Bank, the LED-based jaundice treatment device funded by the non-profit technology incubator D-Rev, and the portable irrigation pump developed by the non-profit KickStart are examples in the social entrepreneurship sphere. Apple's iPad, iPhone, and iTunes music store are illustrative corporate entrepreneurship examples. How do teams of people coalesce in the cauldron of innovation? Engineering skills have a place, certainly, but how do Apple's Steve Jobs, Tim Cook (COO and acting CEO), and Jonathan Ive (Senior VP of Industrial Design) aptly find, develop, and direct teams of engineers? Focusing on creating and operating within organizations of people (rather than products they produce) might be of greater importance now and in the future. How does the undergraduate engineering curriculum relate to motivations to pursue engineering as a major and a profession, as well as the development of profes-

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sional and problem-solving skills within the context of innovation and entrepreneurship? When considering the undergraduate engineering experience as a training ground, what skills and abilities are developed beyond the classroom? More specifically, what undergraduate experiences map to entrepreneurial work?

The importance of professional skills within engineering education has been increasingly recognized by ABET accreditation criteria [1] and the National Academies' *Engineer of 2020* [2]. Drawing on extensive, national research conducted as part of the Center for the Advancement of Engineering Education [3], we examine engineering undergraduates' development of the latter areas of skills and knowledge, focusing on the question, 'How does contemporary engineering education prepare engineering students for entrepreneurship, and what factors are key to fostering future entrepreneurs?'

In this paper, we consider the extracurricular activities of undergraduate engineering students and how their views on and experiences outside the classroom might be related to innovative and entrepreneurial endeavors. By highlighting student activities outside of formalized classroom instruction, the proclivities of students engaged in both engineering-related and non-engineering extracurricular activities can be characterized and examined.

2. Related work

2.1 Extending the academic pathways study

This paper directly extends work done by the Center for the Advancement of Engineering Education through the Academic Pathways Study (APS) [4, 5]. APS encompassed a series of cross-sectional and longitudinal studies designed to investigate undergraduate engineering students' educational experiences. This paper's primary data set consisted of responses from engineering majors who participated in the APS's Academic Pathways of People Learning Engineering Survey (APPLES) [6]. APPLES included questions concerning extracurricular activities, as well as those addressing aspects of student development related to entrepreneurship, as detailed later in this section. Quantitative analyses of these survey data are supplemented by preliminary analyses of interview data collected from another set of engineering undergraduates, the APS Longitudinal Cohort.

2.2 Attributes of entrepreneurs

A wide range of attributes is important to successful entrepreneurship. The engineering entrepreneur needs much more than only domain expertise in relevant areas of engineering. The present work focuses on three categories of entrepreneurial attributes, as examined in the APPLE survey:

- Motivation: interest in engineering and/or entrepreneurship.
- Professional skills: attributes related to communication, teamwork/leadership, and business skills; includes development of a professional/social network.
- Problem-solving skills: characteristics and behaviors related to creativity and innovation in problem-solving.

Prior research has examined how the characteristics and behaviors in the above categories relate to entrepreneurship, as well as to each other. Dyer et al.'s [7] review of recent research concludes that entrepreneurs are similar to successful business executives, at least with respect to locus of control and risk taking. Related to locus of control, Becherer & Maurer [8] found that entrepreneurial activity and success—that of small-business presidents, in the case of their study—were both related to the proactive nature of their presidents, where proactivity was defined in terms of taking action to influence their environments. Beyond attributes, Dyer et al. [7] found that a variety of behaviors distinguish innovative entrepreneurs (*e.g.*, Jeff Bezos of Amazon, Michael Dell of IT corporation Dell) from other business executives: questioning, observing, experimenting/exploring, and idea networking (within a professional/social network). Additionally, underscoring the roles of creativity and innovation in entrepreneurship, Zampetakis's [9] study of engineering and business students found that entrepreneurial ambitions, creativity, and proactivity are all interrelated. Similarly, Amabile's [10] componential model of the creative problem-solving process unifies a variety of the above entrepreneurial attributes and behaviors. This model identifies three internal (*i.e.*, within the individual) components necessary for creativity: intrinsic motivation, domain-relevant skills, and creativity-relevant processes (including risk-taking and approaching problems in multiple, novel ways).

In addition to the above research, the curricula and learning outcomes of existing engineering entrepreneurship programs such as those at the University of Pennsylvania, Pennsylvania State University, North Carolina State University, and Brown University [11] reflect the importance of a wide range of skills and knowledge.* These include professional skills such as team leadership, marketing, and craft-

* See http://www.seas.upenn.edu/entrepreneurship/, http://www.e-ship.psu.edu/, http://www.engr.ncsu.edu/eep/, and the cited paper, respectively, for more information about these programs.

ing business plans, as well as problem-solving and creative skills such as product design. A growing body of research examining the impact of such programs suggests that they are successfully facilitating the development of professional skills, as well as technical skills [12].

In engineering and other disciplines, the general importance of the entrepreneurial student attributes described above are reflected in guidelines issued by higher education organizations such as the Association of American Colleges and Universities (AAC&U). The AAC&U's 'essential learning outcomes' for contemporary liberal education [13] include such skills as critical and creative thinking, teamwork and problem solving, intercultural knowledge and competence, and integrative and applied learning—competencies that are clearly relevant to preparing engineering students to be entrepreneurial in a global environment.

2.3 Extracurricular activities

While acknowledging the role of curricular educational experiences in developing entrepreneurial characteristics and behaviors, we chose to focus on how extracurricular experiences might be related to motivation, professional skills, and problem-solving. General and engineering-specific research points to the significance of extracurricular activities, *e.g.*, in their influence on persistence [14] or in their value in predicting student confidence, as found in earlier APS APPLES analyses [6]. Participation in extracurricular activities such as undergraduate research, service and community-based learning, study abroad, and internships represent the kinds of 'high-impact practices' that have been identified by Kuh and his colleagues [15] through their extensive work with the National Survey of Student Engagement (NSSE) as being particularly effective in increasing rates of student retention and student engagement, being beneficial for college students of all backgrounds.

This paper contributes to literature on the role of extracurricular activities in the educational experiences of undergraduate engineers by building directly on previous extracurricular-related APPLES analyses. Specifically, we examine the potential for engineering and non-engineering activities to facilitate preparation for entrepreneurship in engineering fields.

3. Methods

3.1 Quantitative and qualitative data from the academic pathways study

We employed a concurrent embedded mixed-methods study design [16], where the primary analysis was quantitative, and the qualitative analysis supplements and suggests explanations for the quantitative results. Over 4,200 undergraduates at 21 U.S. institutions participated in APPLES, which was administered in spring, 2008. The quantitative analyses reported here are of multiple-choice responses from 2,143 junior- and senior-level engineering majors. We chose to restrict analyses to juniors and seniors to focus on the experiences and attributes of students who were advanced enough in their program of study to be more likely to complete their engineering studies, compared to first- and second-year students.

Analyses of the quantitative data are supplemented by preliminary analyses of semi-structured interviews conducted in 2006–2007 with a sample of 29 senior-level engineering students in the APS Longitudinal Cohort. These students participated in a four-year, multi-method, longitudinal study of their engineering education experiences. The present analyses focus on their extracurricular experiences and were motivated by questions that the quantitative APPLES analyses raised but could not directly address. Our preliminary treatment of the semi-structured interviews began with reading the transcripts, identifying passages related to extracurricular activities. This was followed by inductive analysis of the passages, with a focus on descriptions of why students engaged in them and what they felt they gained from their involvement. Quotes presented in Section 4.2 illustrate themes in students' discussions of extracurricular activities.

3.2 Examining correlations with extracurricular involvement

This paper explores potential relationships between entrepreneurship and participation in different kinds of extracurricular activities. To this end, we examined the extent to which involvement in extracurricular activities correlated with a variety of attributes of students and their engineering education experiences. Specifically, we sought correlates of their self-reported level of involvement in the following kinds of extracurricular activities:

- Student *engineering activities*, such as engineering clubs or societies (response scale: no involvement, limited involvement, moderate involvement, extensive involvement)
- *Non-engineering activities* on or off campus, such as hobbies, civic or church organizations, campus publications, student government, social fraternity or sorority, sports, *etc.* (response scale: never, rarely, occasionally, frequently)

In order to maintain wording consistency with directly preceding questions in the APPLES instrument, as well as with prior, related instruments [17], the response scales for these two questions were different, but both represent continua of level of involvement.

Our focus is on the subset of APPLES variables [18] below, selected for their relationship to entrepreneurship:

- *Intrinsic psychological motivation:* motivation to study engineering for its own sake, *e.g.*, because it is fun, interesting, or makes one happy
- *Social good motivation:* motivation to study engineering due to the belief that engineers and technology improve the welfare of society
- *Mentor influence motivation:* motivation to study engineering due to the influence of mentor(s), *e.g.*, faculty, advisors, and teaching assistants, as well as non-university affiliated mentors
- *Confidence in professional and interpersonal skills:* confidence in one's abilities in business, public speaking, leadership and teamwork, as well as communication skills and self-confidence in social situations
- *Perceived importance of professional and interpersonal skills:* perceived importance of business, public speaking, leadership and teamwork abilities, as well as communication skills and self-confidence in social situations
- *Confidence in solving open-ended problems:* confidence in one's creativity, critical thinking skills, and ability to engage problems with multiple solutions

For a complete list of variables in APPLES, including the survey items of which they were comprised, see the technical report [6]. Table 1 illustrates our mapping of the selected APPLES variables to the three categories of entrepreneurial attributes given in Section 2.

With one exception, we expected each variable to map to one category of entrepreneurial attributes. We associated intrinsic psychological motivation with both motivation and problem solving, because Amabile's model of creativity [10] identifies motivation as a precursor to creativity.

For each of the two kinds of extracurricular involvement (engineering and non-engineering), we tested for correlation with the above entrepreneurship-related variables using the non-parametric Spearman's rho, which determines the relationship between two variables on interval scales.

In addition to examining the above variables, we examined two APPLES measures that capture specific kinds of extracurricular experience: industry exposure (*e.g.*, internships and co-ops) and research. The former was analyzed using Spearman's rho, and we used a one-way ANOVA for the latter, to compare relationships across different types of research involvement (engineering, non-engineering, or both).

4. Findings

4.1 Correlates of engineering and non-engineering extracurricular involvement

APPLES variables concerning engineering and non-engineering extracurricular involvement, and exposure to the professional engineering environment as visitor, intern, or employee represent a range of extracurricular experiences that might contribute to the development of entrepreneurial attributes, such as the professional and interpersonal skills and open-ended problem-solving abilities described above. Involvement in and exposure to these kinds of experiences are positively associated with certain motivational factors and confidence levels in these skills.

As shown in Table 2, the cluster of motivation variables (social good motivation, mentor influence motivation, and intrinsic psychological motivation) is positively associated with engineering extracurricular involvement and exposure to the professional engineering environment.

Involvement in undergraduate research has been identified as a high-impact practice that influences student retention and engagement and potentially the development of initiative, project management, teamwork, problem solving, as well as other professional skills. A one-way analysis of variance was conducted to evaluate how varying types of involvement in undergraduate research (*e.g.*, no research experience *vs.* involvement in engineering research, non-engineering research, or both engineering and non-engineering research) would affect the variables related to entrepreneurial skills.

As shown in Table 3, students who participated in

Table 1. Mapping of APPLES variables to the three categories of entrepreneurial attributes examined in this paper.

APPLES variable	Motivation	Professional skills	Problem-solving skills
Intrinsic psychological motivation	√		√
Social good motivation	√		
Mentor influence motivation	√		
Confidence in professional and interpersonal skills		√	
Perceived importance of professional and interpersonal skills		√	
Confidence in solving open-ended problems			√

Table 2. Correlations between extracurricular experiences and entrepreneurial attributes ($N = 2{,}143$; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

APPLES variable	Engineering extracurricular involvement	Non-engineering extracurricular involvement	Exposure to professional engineering environment as visitor, intern, or employee
Intrinsic psychological motivation	0.126***	–0.018	0.079***
Social good motivation	0.158***	–0.010	0.051*
Mentor influence motivation	0.193***	0.154***	0.172***
Confidence in professional and interpersonal skills	0.158***	0.200***	0.209***
Confidence in solving open-ended problems	0.106***	0.070**	0.129***

Table 3. Means and standard deviations of entrepreneurial attributes by type(s) of research involvement (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

APPLES variable	No research mean (SD) $n = 1041$	Engineering research mean (SD) $n = 635$	Non-engineering research mean (SD) $n = 155$	Engineering & non-engineering research mean (SD) $n = 300$
Intrinsic Motivation Psychological***	78.0 (21.9)	82.7 (19.3)	78.8 (22.4)	82.6 (20.1)
Social good motivation**	73.6 (23.7)	77.7 (21.1)	76.0 (23.2)	75.9 (23.4)
Mentor influence motivation***	32.6 (24.7)	40.6 (26.2)	35.4 (26.0)	41.2 (27.3)
Confidence in professional and interpersonal skills***	66.9 (16.3)	70.4 (15.9)	68.3 (15.7)	70.7 (15.9)
Confidence in solving open-ended problems**	76.7 (15.4)	78.9 (14.4)	78.8 (14.1)	79.9 (15.4)

research activities, particularly those related to engineering or both engineering and non-engineering research, report higher means in entrepreneurial attributes such as confidence in professional and interpersonal skills, as well as solving open-ended problems, as compared to students who did not participate in any research activities.

4.2 Details of extracurricular involvement

The above analyses suggest positive relationships between specific entrepreneurial attributes and involvement in extracurricular activities (engineering and non-engineering alike). The statistical tests alone do not indicate direction of influence, so they naturally lead to questions concerning the nature of the relationships between extracurricular involvement and entrepreneurial attributes. The remainder of this section describes preliminary observations from interview data, grouped by theme, that address these questions. These interviews also provide a more concrete, detailed picture of the range of specific activities that engineering students choose to engage in.

4.2.1 Engineering extracurricular activities

Students' engineering-related extracurricular activities spanned categories such as affiliations with student engineering groups, engineering-related outreach activities and professional engineering societies and internships. Students reflected on these different categorizations, speaking about differing motivations for involvement, as well as different results from their efforts.

Motivation and Community: Students talked excitedly about their involvement and leadership in expanding their social and professional networks with other students within engineering student organizations. Building community among peers was a main benefit expressed. Dana, a senior majoring in chemical engineering, discussed her time with the student chapter of the Society for Women Engineers:

> And then, SWE [Society for Women Engineers] has helped me, not specifically with chemical engineering so much, but with just providing a network of women who support each other in engineering and give them a professional sense of identity, so that they're more empowered as women in the work force, and what it means to be a woman engineer, and all these resources that they have, and the workshops that they have on leadership, and organizing the meetings that they have, and just being in engineering, what that means, and your role in society and what it means to be a woman in the workplace that's dominated by men still. —*Dana*

Peer support for Dana was available through SWE in ways that were not available through other contexts. Networking and a sense of community came from informal groups, as well. Simon, a senior studying aeronautics, found professional and social community in his fellow student co-workers at an experimental engineering test facility on campus:

> I consider the [test facility] crew as being another group. We actually had just a big end-of-the-year barbeque on Sunday . . . We all kind of have a set group inside the aeronautics community essentially of [test facility] kids. —*Simon*

Such affinity groups, whether formal or *ad hoc*, provided space and room for students to explore their identities as engineers and to reflect with their peers. Under the auspices of academic exploration, there was a safe cover to build relationships, follow interests, and explore a personal meaning for their interest in being engineers. Within a group of fellow students facing these concerns, such exploration allowed for sharing, mentoring, and support for individuals and their motivations for doing engineering. Dana found this with the supporting network of women in the chapter of Society for Women Engineers, and Simon, with his work group at the test facility.

Similarly, shared experiences and goals also seemed to be the impetus for student groups taking engineering out to the surrounding communities through outreach activities. Nate, a senior in chemical engineering, talked about starting a service-learning outreach group:

> I also ended up starting a nonprofit organization . . . a student group [for computer tutoring in K–12]. Started that at the end of sophomore year. *—Nate*

Creating an outreach group to fulfill a perceived need was something inspiring to Nate and gave an opportunity for his interests to excite the spirit and imagination of others. It was also an opportunity to share disciplinary knowledge with others and get feedback. Hillary, also a senior in chemical engineering, tutored elementary school children in math and science and described how she enjoyed this experience:

> I'm tutoring a 3rd-grade class and a 6th-grade class. And mostly it's math and science. I've done some English with the 6th-graders and stuff like that. But it's really fun. Basically, basically I'm working in the 3rd-grade class, but really I go in and play. *—Hillary*

Gaining engineering work experience: In contrast to sharing interest in engineering, gaining engineering work experience, understandably, was an avenue to be exposed to what engineering work practice and applications were like. Simon explained the value of his research internship working at the test facility in terms of benefits to his extrinsic motivations:

> . . . there's absolutely no way I would be anywhere close to where I am in my education and in my professional career had I not worked at the [test facility]. Not only is it a great job experience working with that team, but just the stuff that I've learned. I've gained such a great knowledge from not only working there but talking to all the customers that come through and talking about their designs a general idea of how the [aeronautics/aerospace] industry works. And it's definitely put me ahead. I've also gained interviewing skills. 'Cause there's not many college students that get to interview hires, especially not anything long term like I've been doing . . . And of course it looks good on a resume . . . *—Simon*

Thus, in addition to gaining a sense of community from his extracurricular involvement, Simon was also able to develop professional skills and bolster qualifications for the future. He was also cognizant of the value of having such an experience on his resume.

Additionally, some participants reflected on applying engineering work in context as a means to further fuel their curiosity and motivation. Oscar, a senior electrical engineering student, reflected on his computer consulting work experience as a learning opportunity and the satisfaction it can bring:

> I go to work; it affirms that what I've been learning is actually useful to someone. That in turn encourages me to learn more, which in turn makes me come back and say, 'Wow, I really want to learn more about embedded systems, because there's a lot of work that needs to be done in embedded systems.' So it's the same application thing. It's the encouragement that you get from knowing that what you're doing is useful to somebody to do something, rather than just—problem sets are great—well, no, they're not—but everyone's doing the same problem set, and everyone turns it in the box, and you get marked 'yes' or 'no,' 'right' or 'wrong.' And it's really not the same as producing something that's a unique problem that, once you've done it, it's solved. *—Oscar*

A take-away for Oscar was his reflection on how problem solving happens in the classroom and in the working world. He characterized real-world, open-ended problems as compelling engineering work, in direct contrast to problem sets he encountered in school.

A Professional Obligation: Students connected with professional engineering societies in their majors and areas of interest. Their commitment was light, participation depending on the convenience of the meetings or availability of food as the main rationale for attending. Growing a professional network was recognized as a resulting effect, though excitement about attending was muted.

Preston, a senior in petroleum engineering, recounted his involvement:

> . . . the academic groups I have been in is the Society of Petroleum Engineers, and the Association of, or the American Association of Drilling Engineers. And those are both pretty good groups. The SPE, the Society of Petroleum Engineers, they try and bring in a guest speaker once a month. And it will be on a Wednesday at noon, and they give a lecture or like a presentation on something new that's happening in the industry or something interesting. And gives us a chance to ask questions about it, and there'll be a pizza lunch. And then quarterly, the American Association of Drilling Engineers, they'll do a big dinner downtown. Professionals will go to this and they'll actually pay for the students to come. So it's good interaction between students and professionals. And there'll be a professional giving a presentation on something new again that is going on. *—Preston*

The passive manner in which students talked about these engineering professional societies could indicate that they were perceived as either *de rigueur* obligations or useful activities with more long-term than short-term benefits.

Summary of Engineering Extracurricular Involvement: This menu of engineering-related activities goes to show distinct possible motivations for engagement in extracurriculars. The extracurriculars with a department-led structure addressed student desires for exploring work and professional networking. Students seemed to treat them as extensions of their commitments to their areas of study, relying on others (companies, societies) to provide the schedule and structure. Student-led engineering extracurricular activities, whether as student-led formal groups, *ad hoc* assemblages of affinity groups, or outreach groups evolving out of a distinct mission, seemed to make for a different sort of student involvement—one more out of individual, immediate interest and need.

4.2.2 Non-engineering extracurricular activities

Student involvement in non-engineering activities reflected an array of activities. From individual pursuits and hobbies, to social fraternities and social communities, to outreach, and other ways to explore personal and professional boundaries, the gestalt of this broader range of activities came more directly out of personal interest.

Personal Interests: A fair number of students had very individual and personal interests that complemented their mainstream engineering activities. Students were not always comfortable with this duality, and it was often a source of unresolved tension. Anna, a senior in material science, for example, struggled with how art fit into her interests:

> There's a constant struggle with me and art. Because I love it. And it's a part of who I am. And, I wish I could do it more, you know. Hopefully, when I grow up, or if I ever grow up, I don't know. That I will create a life for myself where I do have that ability to, you know, if you have a job, and you don't have homework, then maybe you can paint, draw or whatever. Making it a job might completely change it for me. Because, I wanna do what I wanna do . . . And so making it a career would probably be a bad idea, 'cause I'd end up making myself hate what I love. So, I think I, I need to keep that as, as something for me. —*Anna*

Simon too, set aside notions of following an interest in performing music professionally. Leveraging a practical side, he characterized music as a hobby:

> I couldn't see myself doing that as a career. It's more of a side fun thing not to sit down and labor through stuff all the time music wise. I sit down and labor through stuff all day but not in that way. —*Simon*

They both waxed over how to resolve their dilemma. Others, like Joe, a senior majoring in computer systems engineering, were goal-oriented and passionate about a personal project, not concerned with how real or practical or immediate it was to their studies:

> I make medieval chain mail armor. It's a good thing to do when you have the time, and now I have a little bit of time, so I can do it . . . What I end up doing—I make all my own rings. I buy bulk steel wire, and then I coil it up and cut it into rings and then assemble all of them. Well, they're just mint [stamped] together. I mean, I use heavy enough wire that it's strong enough. Well, on the piece that I'm working right now, I've probably got two or three years left before it's done, just because I'm making something that's really high quality, really nice. I figure if I'm going to put all this time in, I might as well have something to be proud of when I'm done. —*Joe*

Students had varied interests, and most were driven by a seemingly innate desire to fulfill their own facets of interest. Joe was quite determined and resolute with his metal smithing. For Anna and Simon, however, their pursuits of art and music were sources of tension and were seen as problematic, and they yearned to reconcile them with their engineering pursuits. They were not yet extracurricular activities that squared with their engineering work.

Social Connections: Additionally, students talked about opportunities taken to join non-engineering affinity groups, particularly Greek organizations. In their descriptions, these were means to practice building social rapport and establish social capital within a community. For Bryn, a senior in technical communication, joining a social organization was also surprising (to her), per her account of how she got involved with her sorority:

> The sisterhood [rocks] and amazing bond between these women so . . . I got a call from one of my friends who I had worked with one summer and . . .she's in a sorority. At first I was like, 'No,' I didn't want to do anything like that. And then she started talking to me more, and she told me the principles, and what they stood for, the philanthropies. And it sounded really good. I had been, I didn't have a lot of close girlfriends, I don't have any sisters. I have a lot of guy friends, and I didn't have a lot of close girlfriends on campus. So I was, 'It might be a good thing.' And so I looked at it more and started hanging out with them, and that's how I became interested and started forming bonds with these girls. —*Bryn*

Other social groups served as ways to build social capital through supporting or fostering identity, community, and belonging, both individually and in support of others. Religious and cultural activities, in particular, were important in some of these regards, as described here by Oscar and Kevin (a senior in electrical engineering):

> [Church music] meant a lot to me because it let me be more involved in the church. It allowed a lot of other

> people to be involved in the church. And it pulled a lot of—I mean, that mass was always a very kind of a quiet, historically had been a quiet mass, where people were not terribly involved, but it has become a much more, open and inviting—I don't want to say open and inviting—but a lot more involved. And I think that that has a lot to do with, different ways students get involved, and part of that has been this choir, which I've really put a lot of work into making it a place, an opportunity for people to be involved in the church, and I've seen it work. So, that's one of my favorite activities that I've done . . . —*Oscar*

> I've been involved to some extent with the Islamic Society . . .and then also the [Muslim student organization]. And then, just like, the first organization is kind of like more of a religious, cultural kind of group, and they just hold, like, regular events on, like, things of religious interest. And so, I mean, my attendance has varied a lot, but I'm still, like, part of that community. —*Kevin*

Fostering Leadership: Some opportunities also provided space to explore professional leadership skills, in addition to personal skills and development. Dana, in leading a chapter of a religious advocacy group, found connections to her area of study as well:

> I think that [the school's chapter of] [a religious advocacy group] doesn't have anything to do with chemical engineering, really. Chemical engineers somehow get involved with, and it could, but not really. But I've learned a lot through that, just about bioethics and about a lot of those life issues. So, I've been educated in those areas. And the Catholic community has helped educate me more in my faith and spiritually, and I've become stronger, but I've also had deeper struggles, so it's also showed me how weak I am, as well. So, it's very up and down, but it's been very enlightening, too, just to see other people with very strong faith and to be more educated in the history and the faith, and everything. —*Dana*

Others found secular causes to devote time and efforts. Beth, an environmental engineering senior, described her longstanding volunteering commitments:

> I still do like things that I've done for a really long time. Like I still volunteer at [a homeless shelter]. Which I've actually been doing since like 6th grade. I volunteer at [an AIDS hospice], which I've been doing since 9th grade. —*Beth*

For Dana and Beth, taking on these roles meshed well with their established ideas about how to engage with the world beyond school.

Extending Personal Boundaries: Additional non-engineering extracurricular activities were also fodder for pushing (less serious or consequential) boundaries as well. The school environment can provide opportunities to explore a wide range of non-engineering activities with lower stakes and investment of time than after graduation. For Carl, a senior in petroleum engineering, he could dabble in student politics:

> You know it's, it's great. You just have to, you know it's all a game you know. And I like doing it. It's not like oh, I like playing this game. It's you know I like doing what [student activities council] does. —*Carl*

Carl was actively engaged in such extracurriculars. A last category of students were those engaged in outward-facing activities but who were less active or intentional in seeking them out. Grace, a major in mechanical engineering, for example, recounted a work activity that she found useful, although it was unrelated to engineering:

> For [freshman] summer, I went home and . . . I sold Cutco knives. Yeah. That was interesting learning, 'cause we had to learn about the product. That was pretty cool. Also, it was just hanging out with people, in random people's houses. Yeah. I enjoyed it. It was kind of hard, though, like just having to drive around and book appointments and stuff like that. So I was in sales. —*Grace*

By definition, these activities were all non-engineering related. Each student talked with an amount of excitement or passion about what they did. It might have been expressed with genuine enthusiasm or wonder that it happened. For some the activity was a means to express themselves more broadly than constrained by their engineering work. For others, it was a mechanism to tinker with their self-efficacy in areas they were well practiced or not-at-all competent. Some of the social groups provided support and nourishment for a side not addressed in their engineering work. For some it was just an extension of their engineering selves applied in other domains. All found satisfaction in activities beyond a prescribed norm for engineering majors. These non-engineering-related activities followed passions, personal motivations, and interests, and they supplemented the students' portfolios of engineering activities.

4.2.3 Research experience

Two interviewed students had research experiences they discussed with us. These students described how they encountered novel, open-ended situations that required critical thinking skills. Both students expressed how much they learned about research in their respective fields. Bryn, a technical communication major, was involved in qualitative research. Here, she describes learning about the research process through the coding and analysis of interview transcripts:

> It's been interesting because it's not a process I've been through before, so the first one was kind of difficult 'cause I didn't know what to expect or, sometimes it's just figuring out how to write what I was doing so . . . In the summer, I just started and I didn't even know how to develop codes and how to analyze any of it in [thematic] analysis, so I learned how to—I've never

> read so many documents over and over again . . . I learned how to do the coding and how to develop codes that were significant across the data. And how to represent the data. So, yeah, and summarizing long transcripts and what they have to say. —*Bryn*

Dana was a chemical engineering major who did research for her honors thesis in a biotechnology lab. Her research experience seemed distinct from her chemical engineering studies, both in terms of process and outcome:

> . . . because I was in the biotech lab, so it didn't feel so much like chemical engineering. I wasn't doing, like, a material balance on a flow sheet. I was trying to make some assumptions about a biological system that I was working with and think about how to use, like, chemical tools to analyze what's going on in the system. And so, I was using chemistry and biology, and then just doing some manual processes, like pipetting and, like, cleaning things and stuff . . . And the pace was very different, though. When I would think about working on something for, like, three or four hours, just to get some data points, on the other hand, like, working three or four hours on the problem sets, you know, getting a substantial amount of stuff written down and calculated. So, it looks like there was more work getting done . . . with the problem sets. So, I don't know. Interesting. —*Dana*

On the one hand, she appreciated the research work's social good motivation:

> But I guess the whole thing is that I had a different—like, I had a goal, had a purpose of, like, contributing to an overall project that would develop a water filter. And that would be highly purifying and help people, and all kinds of cool things. —*Dana*

However, she also expressed some dissatisfaction with the isolated nature of the research lab environment:

> And then, you're not even talking to people in the lab, you're just, like, doing what you need to do. I mean, there are people who talk, and you do talk to people a little bit, but you have to concentrate on what you're doing, because . . . otherwise, you'll mess up, like I did sometimes. And at the beginning, I wasn't really talking to anyone, anyway, 'cause I didn't know a lot of people, and I didn't know what the lab dynamics were like anyway, 'cause lots of people didn't talk, necessarily. —*Dana*

In fact, there was some conflict in her mind about the value of her time spent on research. When asked if she would have done anything differently in her undergraduate experience, she replied,

> I think I would have seriously reconsidered the whole research activity. That was—I mean, I'm glad that I did it, I guess, and I'm proud that I accomplished the thesis, but I just wonder what it would have been like, what I would have done with that time otherwise. —*Dana*

These cases show, we believe, the double-edged sword that research experience can represent to the development of entrepreneurial skills. While it can be a great way to learn and gain confidence in open-ended problem solving and critical thinking, the nature of some research settings and the associated time demands can also lead to missed opportunities for the development of interpersonal skills.

5. Discussion

Quantitative analysis of the APPLES responses established positive relationships between the selected entrepreneurial attributes (motivation, professional skills, and problem-solving skills) and a variety of extracurricular activities, ranging from industry and research experiences to non-engineering activities. Engineering-related activities were more clearly linked with motivation, but both engineering and non-engineering activities were linked with professional and problem-solving skills.

Preliminary analysis of interviews added context and richness to the quantitative analyses. Specifically, they suggested that extracurricular activities do indeed facilitate the development of attributes relevant to entrepreneurship. Beyond this, interviews provided evidence that these attributes feed into each other. In both Dana and Nate, we saw how motivation can lead to development of professional skills. By getting involved in her SWE community, Dana gained leadership skills and connected with a professional network, both of which served to strengthen and inform her identity as a woman in a male-dominated profession. Nate demonstrated initiative by starting a student group to tutor local youth, thereby creating an environment to advance his interests in computers and technology, while honing his communication and leadership skills. Similarly, Oscar developed an appreciation for problem-solving skills from his work experience, which he contrasted with the problem sets he was assigned in his courses.

The positive interactions among motivation, professional skills, and problem solving were evident for the students' non-engineering extracurricular activities as well. For Bryn, participating in social organizations and building social capital were keen practice for professional networking. Joe's motivation was evident in his zeal and determination in constructing chain mail. These accounts illustrate how students benefit, directly and indirectly, from their extracurricular involvement in ways that could conceivably contribute to entrepreneurial ambitions and success.

The case of research experience, however, shows that tradeoffs sometimes do exist. In Dana's experience, we saw evidence that the confidence gained in open-ended problem solving and critical thinking skills may have been acquired at the expense of missed opportunities for the development of interpersonal skills.

Our findings suggest multiple ways in which extracurricular opportunities can complement coursework by providing contexts for students to develop attributes with potential value in entrepreneurial pursuits. In these activities, students are exercising and developing personal motivation while leveraging specific experiences to bolster their passion and self-efficacy in engineering and non-engineering endeavors. They are cultivating professional skills and networking skills that would transfer to entrepreneurial contexts. They are developing tolerance (and even a liking) for the ambiguities of real interactions and real problems that demand creative solutions.

6. Future work

Findings from the quantitative analyses highlight the role of out-of-class learning experiences and how they might serve as a context for fostering the development of entrepreneurial attributes. Prior analyses of APS data (including APPLES responses) focused on gender differences in involvement in and importance ascribed to engineering and non-engineering extracurricular activities [19]. A natural follow-up to our APPLES analysis would be to examine how gender and other demographic factors (*e.g.*, socioeconomic status) play into the relationships between entrepreneurial attributes and extracurriculars. We also plan to further expand APS analyses to include specific kinds of attributes (*e.g.*, approaches to open-ended design problems) and curricular experiences (including team projects), both of which relate to the entrepreneurial attributes examined in this paper.

As a means of further examining causal relationships between extracurricular involvement and student attributes, statistical modeling has been applied to the APPLES data set in cases where reasonable assumptions of causal direction can be made [6]. Future work could employ a pre/post design to further delineate the specific conditions that contribute to entrepreneurial attributes. Possible models from the Association of American Colleges and Universities (AAC&U) address how learning outcomes such as creative thinking or entrepreneurial abilities can be measured through, for example, the use of rubrics.* These rubrics articulate the criteria to evaluate evidence of student learning for outcomes that cannot be easily measured through traditional methods such as standardized tests. Electronic learning portfolios (ePortfolios) are another assessment approach that could be implemented in courses or across an engineering program to partner with students in a collaborative effort to gather more authentic evidence of entrepreneurial skills and abilities as they develop across curricular and extracurricular contexts over time. With increased interest in and relevance of engineering-focused entrepreneurship education, further studies and assessments of how curricular and extracurricular experiences prepare students for entrepreneurial success are necessary in order to inform the design and evaluation of such programs.

In a direct extension of APS research, we recently interviewed a subset of Longitudinal Cohort participants, five years after they graduated. A preliminary analysis of this interview data indicates that internships during undergraduate years were an important part of the learning experience for some people. One individual reported, '. . . I started [on] the ground in the field and . . .did a lot of internship[s] in college and saw a lot of different portions of the business . . .', and a second individual stated, '. . . my internship . . . was helpful as far as learning more about how an office works and everything and how to, I guess, coordinate with superiors and stuff.' Future analysis of this data will include a focus on how undergraduate extracurricular activities may have impacted individuals' careers.

Finally, given the interest in social good reflected in the APPLES and Longitudinal Cohort participants, research and teaching efforts could help prepare engineering undergraduates to face the unique challenges at the intersection of engineering and social entrepreneurship [20]. For instance, professional and interpersonal skills might help engineers effectively act on their good intentions and avoid unintended consequences in social entrepreneurship efforts. These skills are essential for establishing and sustaining the kinds of relationships with partner communities that provide a deep, contextualized understanding of their needs. In general, this line of future work might provide an improved understanding of how specific kinds of motivation and skills can be applied (and misapplied) in engineering entrepreneurship, whether for business, social good, or both.

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* See http://www.aacu.org/value for relevant resources.

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