

Engineering Competitions as Pathways to Development of Professional Engineering Skills

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Abstract

In this paper we present preliminary findings from a research project aimed at identifying learning outcomes in informal environments. We focused on engineering competitions which have gained momentum across a range of engineering disciplines. Increasingly, students are participating in design competitions that range anywhere from multi-year activities such as Concrete Canoe and Formula SAE to short term activities such as one day competitions or Hack-a-thons. Although competitions are becoming popular, there is little research on what students learn through their participation in these events. Proponents of competitions argue that these activities provide students the opportunity to apply both technical and professional skills and knowledge to a practical or applied problem and through their participation improve their skills or knowledge, i.e. learn. To empirically examine this issue we conducted a qualitative study in one engineering competition. We examined students' experiences of developing professional skills. The purpose for this study was to understand how students conceptualized professional skills as they engaged in the competition. Findings indicated that professional responsibilities were discussed most often as cognitions, behaviors, and dispositions. We organized these into three broad categories: self-management, task management, and team management, which can be used as a framework for future research. By providing students the opportunity to own the problem and its outcomes, engineering competitions can empower students to think like, act as, and become professional engineers.

Introduction

Engineering is a professional discipline. Engineers work largely within professional codes of conduct and are often required to obtain professional licensure to practice. As a professional, they are not only required to abide by certain codes – such as ethics – but are also expected to gain skills such as being able to communicate effectively, understand societal implications of their work, and continuously improve their knowledge as novel techniques and tools are developed and deployed in practice. For undergraduate engineering students, opportunities to engage in problems and tasks that would allow them to develop these skills are critical. Although the need for such experiences is well recognized, providing such authentic experiences, has also been one of the highest barriers in engineering education (Spradling, So, & Anson, 2009). Therefore, providing evidence that engineering competitions provide powerful learning experiences may act as a motivation to address the barriers.

One educational experience that has been implemented across engineering degrees is engineering competitions. In recent years, competitions have found favor among schools and universities especially because competitions provide hands-on experience. Engineering competitions provide students with the opportunities to participate in authentic tasks, to become engaged in planning and design, to solve complex problems, and to work with teams (Carberry, Lee, & Swan, 2013). In a previous study, Kusano and Johri (2014) found that engineering competitions supported the development of student autonomy, and the developing autonomy provided students a sense of empowerment over their own learning trajectories. The Kusano and Johri (2014) findings support examination of the broader scope of professional responsibilities and the acquisition of professional skills and knowledge. Autonomy and a sense of empowerment about one's own personal learning trajectory may provide support for learning with competitions.

Engineering competitions may also create an environment to promote effective learning. For example, students have the opportunity to conduct research within the context of a competition (e.g., Hetawal, Gophane, & Mukkamala, 2014). Ideally, an effective learning experience within an engineering competition would act as an affordance for students to apply content knowledge and skills to develop deep conceptual understanding. In addition, students would acquire proficiency in technical and professional skills and workforce competencies as they solve authentic engineering problems (Bement, Dutta, & Patil, 2015; Kolmos & de Graaff, 2014; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). Koehn (2006) found that students who participated in the steel bridge and canoe competitions specifically believed that the competition enhanced their understanding and application of technical and professional skills. Thus, engineering competitions may act as a catalyst for students to learn how to integrate technical and professional skills and knowledge in their development as an engineer.

Although competitions provide a range of experiences and competencies, professional skills development are foundational competencies assessed within engineering (American Association for Engineering Societies [AAES], 2015), which is the main focus of this paper. Professional skills comprise six outcomes for engineering students as defined by the Accreditation Board for Engineering and Technology™ (ABET, 2013). Shuman et al. (2005) expanded on the ABET definitions and grouped the skills into process and awareness skills. Process skills included an ability to function on multidisciplinary teams; an ability to communicate effectively; and an understanding of professional and ethical responsibility. Awareness skills included the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context; a recognition of the need for, and an ability to engage in life-long learning; and a knowledge of contemporary issues (Shuman, Besterfield-Sacre, & McGourty, 2005). The Shuman et al. (2005) discussion of professional and ethical responsibility clearly discussed ethical responsibilities within the scope of an overall professional responsibility. In earlier work, Besterfield-Sacre et al. (2002) delineated professional traits as professional image; positive work ethics; independent learning, thinking, and motivation; continued desire for learning; and being goal-oriented, organized, and able to manage time (Besterfield-Sacre, Shuman, & Wolfe, 2002). AAES identified professionalism as a foundational, Tier 1 personal effectiveness competency and professional ethics as a Tier 4 Industry-Wide Technical Competency in their Engineering Competency Model (2015). As with any categorization process, different points of view exist in the engineering community about the composition of professional skills (Gilbuena, Sherrett, Gummer, Champagne, & Koretsky, 2015). However, for the purposes of better understanding the impact of educational environments, skill categorization does provide a means to determine how these skills can be assessed.

Research Questions

We examined students' cognitions about their experiences in an engineering competition, specifically related to professional skills as identified by ABET (2013) and as organized by Shuman et al., (2005). We investigated the following research questions:

1. What is the incidence of students' dialogue about professional skills, as defined by the ABET student outcomes, when students reflect on their experiences within engineering competitions?
2. How do students describe their experiences and understandings of professional and ethical responsibility?
3. What are the key attributes of professional responsibility within an engineering competition?

Methods

This study was primarily a qualitative study. Data were collected from undergraduate engineering students participating in the IAM3D Design challenge, which was a non-curricular engineering competition. The students were required to design and fabricate a remotely-piloted hybrid ground and air vehicle. We used descriptive statistics to address RQ1. Based on the results, we mapped out the terrain of how students experienced professional responsibilities within engineering competitions. For RQ2 and RQ3, we used a phenomenological approach to guide analysis and interpretation. Phenomenology is ideally suited to examine practice and can be used to study individual experience within focus groups sharing a collective experience (Asunda & Hill, 2007; Bradbury-Jones, Sambrook, & Irvine, 2009; van Manen, 2014).

Sample

This study took place in a large public university in the U.S. with a highly ranked and subscribed engineering program, more than 10 engineering majors, and a robust selection of clubs and other organizations to support engineering education. This university also hosts multiple engineering competitions. We drew focus groups from undergraduate engineering students in the IAM3D challenge, which lasted for 10 weeks. The students worked on self-identified projects in teams approximately 50 students participated in the competition. Teams of students ranged from approximately two to four pending maintenance of participation throughout the competition. Students came from various engineering disciplines, and represented all stages of an engineering undergraduate career. All students participating in the competition were invited to participate in the focus groups. Eighteen students participated in the study. Three were female.

Data Collection

Focus groups provided insight into the rich experiences of engineering competitions, specifically the similarities and differences across individual experiences of professionalism (Ryan, Gandha, Culbertson, & Carlson, 2014). Nine focus groups were conducted across the year. Four to seven students participated in a given focus group. Sample protocol for the focus group included questions such as: “How would you describe your process?” “What would you want a potential employer and/or your engineering professors to know about your experience with the competition?”

Analysis

Student comments were coded for each of the six ABET professional skills and were quantified with descriptive statistics to answer RQ1. To address RQ2 and RQ3, all comments initially coded as “professional and ethical responsibilities” were reviewed to identify the meaning for each student response and assigned a thematic code (Colaizzi, 1978). Initial analyses revealed that student dialogue focused on their developing understandings of professional and ethical responsibilities. Therefore, we focused on understanding students’ experiences of professional and ethical responsibilities using phenomenology as the interpretive framework (van Manen, 2014). Several themes within professional and ethical responsibilities were identified and quantified with descriptive statistics. These themes were identified as specific skills, grouped into meaningful categories, and organized as a framework of professional and ethical responsibilities.

Findings

As framed by Shuman et al. (2005), process skills comprised 72% of the student dialogue and awareness skills 28%. Within the process skills and across all of the six ABET professional

skills (2013), professional and ethical responsibility was discussed most often. Figure 1 shows the incidence of the discussions of experiences with the ABET professional skills.

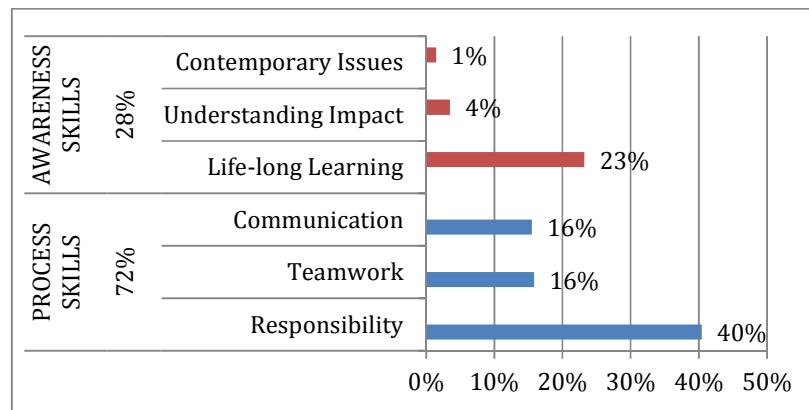


Figure 1. Percent of ABET Professional Skills

Within the discussion of professional responsibility, students did not use words, such as “professional responsibility,” or “ethical.” Rather, the students spoke in terms of cognitions, behaviors, or dispositions expected of an engineering professional. Three thematic categories emerged: self-management, task management, and team management. Self-management was discussed in 62% of the comments. Self-management was discussed as the skills needed to maintain participation in the competition while completing their studies. Task management was discussed in 32% of the comments. Task management was discussed as the skills needed to accomplish the engineering tasks in the competition. Team management was discussed in 6% of the comments. Team management focused on leadership of a group or groups of students to accomplish one or more tasks within the competition. Figure 2 shows the incidence of comments for each of the professional responsibility categories.

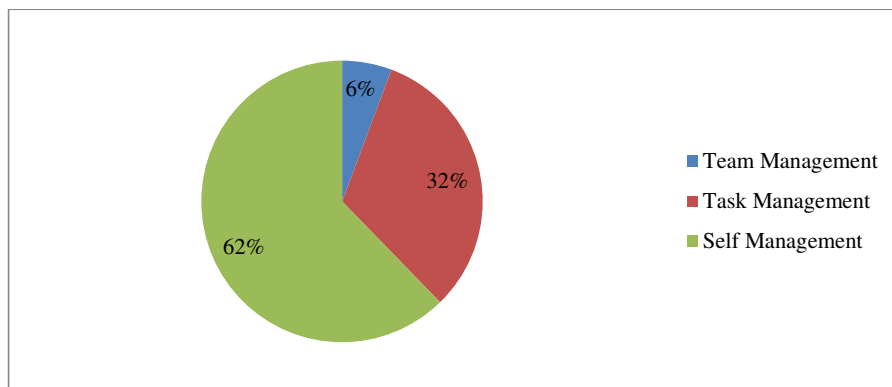


Figure 2. Percent of Professional Responsibilities by Category

Several specific cognitions, behaviors, or dispositions were grouped within each thematic category of self-management, task management, and team management, and are delineated in Figure 3.

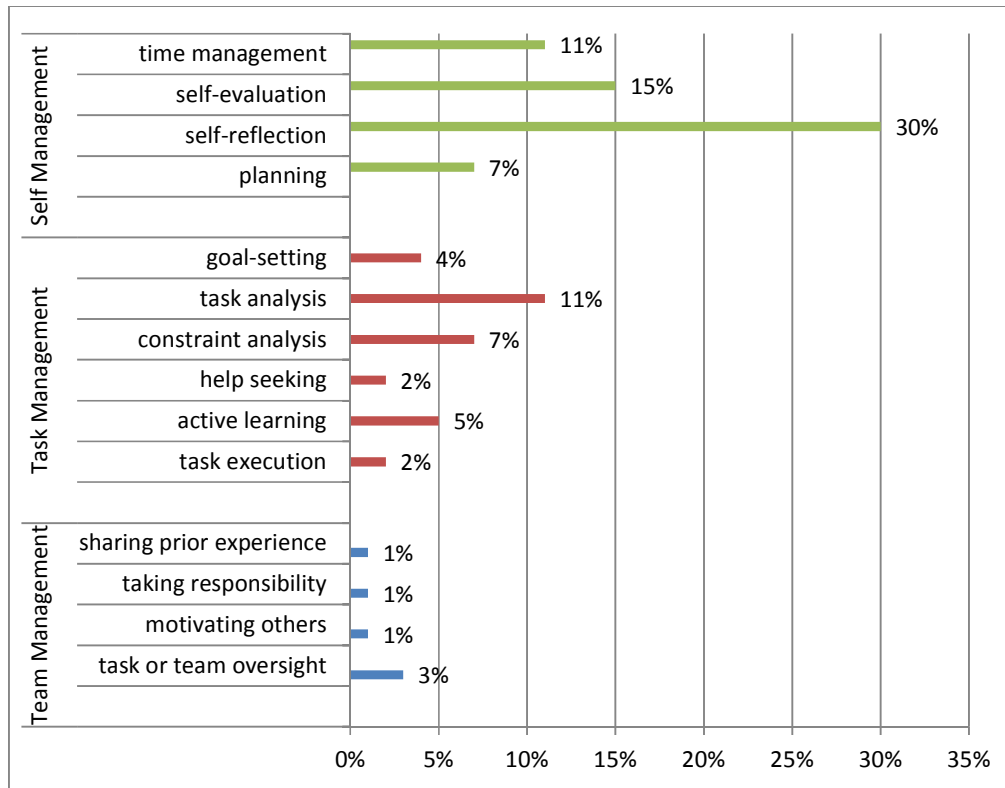


Figure 3. Reported Cognition, Behaviors, and Dispositions within Categories of the Professional Responsibilities.

Self-management

Self-management included experiences dealing with time management, self-evaluation, self-reflection, and future planning. Experiences with time management focused on student experiences about realizing the importance of managing their time in order to complete their project. For most students new to the competition, time management was a realization that occurred during the competition once the students understood the work. Students with prior experience in competitions knew before beginning the competition that time management was necessary. Student self-evaluative comments were content-based and occurred at the micro-level of enacting the tasks. Self-evaluative comments focused on evaluating the process of product development, product design, or the final product. Other comments addressed specific knowledge acquired about building the product or processes to develop the product, such as how design skills improved. Student self-reflective comments were process-based. Students focused on the macro-level in self-reflection as they considered the effects of the competition as a holistic process on their own improvement, as a way of being a professional, such as improving how they worked or supporting the development of their professional dispositions. Future planning discussions addressed students' thoughts about their future, specifically how the competition contributed to their future goals. Table 1 provides illustrative student comments.

Table 1: Sample Student Comments about the Self-Management Category.

| Self-Management | Student Statement |
|------------------------|--|
| Time Management | It's really just having a time table ahead of time, so we can schedule it with exams and things like that, that's one of the biggest things I think. |
| | We would try to get together weekly, for at least an hour, maybe 2.... Try to work on design and work on our electronics and that kind of stuff.... That was a good schedule for us. |
| | For me the lab helps me manage my time. I want to work on my project, and I have to finish everything first... I can't just not do my work and do this. |
| Self-evaluation | My cad skills, they were good in one area before, but now they're more rounded than they were before. As far as just general design goes I think it definitely improved. |
| | For me the lab is a place where I've learned how to do things properly. |
| | I don't have nearly as much experience as basically anybody else in this competition. So it allowed me to learn how to use CAD software, building skills like that ... is huge. |
| | It's more design exposure... I wanted to get more hands-on with that... and this pushed me in the right direction. |
| Self-reflection | I was very much aware of what I didn't know, and I've learned a bit more! |
| | A lot of the projects that you get to work on in school, they're all directed by a class. This was a chance to make it completely self-directed and self-motivated which was a huge driving factor for me. It just added a sense of ownership to the project that you wouldn't get in a normal class, which I found really, really intriguing. |
| | If you have an ambition or a goal, and if you can back the ambition up with hard work, then you can succeed and I think that's been the most meaningful thing... It was a lot of fun, and it was basically all this hard work that we put into these last few months and just seeing people's face light up. |
| Future Planning | I was trying to find my direction. I feel I can do a lot, but trying to find what interests me and where I want to put myself... I know I want to make a little impact, positively. Try to figure out what I want to do, it's my big thing this year. Like what's worthwhile versus what's going to make more money you know? So that's what I'm hoping to find. |
| | I definitely plan on sticking with it, joining the professional chapters next year after graduation and all that. So, I kind of altered my goals a little bit. |

Task management

Task management included experiences focusing on goal-setting, task analysis, constraint analysis, help-seeking, active learning, and task execution. Goal-setting included setting goals to complete the overall task, goals for the product, or broader goals, such as for winning.

Task analysis was integrated with the content of engineering and focused specifically on completing the next steps in the project. Students addressed analyzing the broader project or specific tasks, troubleshooting, and identifying strategies to complete a given task. Constraint analysis addressed examination of the broader project to understand competition regulations, situational parameters, task, design, or problem constraints, or the competition field and how a given situation affected the broader project or specific tasks. Help-seeking included recognition of needing help, acceptance of help when offered, and recognition of the importance of different kinds of help. In active learning, students took the initiative to learn something to accomplish their tasks beyond help-seeking, such as by conducting their own research. Task execution focused on the experiences of students doing a task to accomplish a goal, experiment with an idea, or enact their design. Table 2 provides illustrative student comments related to task management.

Table 2: Sample Student Comments about the Task Management Category.

| Task Management | Student Statement |
|----------------------------|--|
| Goal-setting | I noticed after the first or second meetings that this is the first time I've ever plotted out goals along the way in order to complete a project. |
| | Our original goal was innovation, and I believe we definitely achieved that with our design. |
| | The goal is to consistently win in some fashion, on many fronts. Winning is not just finishing first. It's also having a great education on the team, establishing a legacy. Some, various wins are better than just one large one. |
| Task Analysis | A lot of the batteries that we had installed were failing. It bothered me so much that when we did the analysis I wanted to make sure that with their current loading there's no way they could drain more than 50% of the batteries per day, and we've used that metric to design the last two systems. |
| | Fortunately, we had printed a sample part, before the actual competition, before we sent our final piece out, so we were able to correct it, but like some of the drawing that we were using, basing our designs off of, were the wrong dimensions. So that made the whole thing more difficult. Because we had to wait until we got the kit apart, and we had to measure to make sure everything was correct. |
| | I don't think you have enough time to do this complex of a CAD model within 4 weeks, and be successful. |
| Constraint Analysis | "What was the course going to be like?" "The surface?" <i>That</i> would have a little bit of an impact. |
| | I think the hardest thing was ...the restrictions of the competition. |
| | There's 200 teams ... and we have to stand out. So this really made us think of what we could make that's different, that no one else would come up with. |
| Help Seeking | I would ask questions of Dr. ...He gave me a lot of good suggestions that I needed to do. |
| | He kind of reviews our designs and tells us we need to do this, this will work, this probably won't, go in this direction. So he's a great resource to have. |

| | |
|------------------------|---|
| | Last week we had a grad student come in and talk to us for a while. He was very helpful with moving our project along. But also he emphasized slowing down too, and making sure that you really know how something works before you put it on a larger scale ... [be]cause it will make it much easier...in the long run. |
| Active Learning | I did a lot of research... I had to learn more about quadcopters in general. So I did a lot of research on that online. |
| | Even with those lecture slides, we had them open at many of our team meetings. Looking at all the stuff that we already knew, but we wanted more information. |
| | I joined, and it was kind of intimidating because everyone seems to know what they're doing. Then you're there a little longer, and you figure out no one knows what they're doing. Everyone is kind of learning as they go. And then you learn how to learn. So that's cool. |
| Task Execution | Having that experience of going through designing something and actually prototyping it. I got to make a prototype, and actually building it, which was awesome. |
| | [We] spent a couple months just working on the design. But we spent a while coming up with a good design, because we didn't want to put in time if we knew it didn't work. So we went through all the possibilities of how to make it, so we went through everything. That's why it took us so long. |

Team Management

Team management discussions were less frequent, which was to be expected as not all students were team leaders. Team management included students sharing prior experiences with competitions, tasks, technical or professional skills; taking responsibility for a task; motivating other teammates; or oversight of a group of students working on a task or the project. Team leadership was emergent. That is, student leaders were not appointed by faculty or other students. They were self-appointed, but the students recognized that their self-appointment was emergent. For example, some leaders emerged because they had prior experience in high school or as an undergraduate with the content or materials, or by solving similar problems. Therefore, they felt that they needed to help other students understand the process. Other leaders emerged because their leadership behaviors included a sustained presence in the competition workspace; intra-team and cross-team problem-solving or trouble-shooting; affective support for team members; or being considered by others as the “go-to” person. Table 3 provides illustrative student comments about team management.

Table 3: Sample Student Comments about the Team Management Category.

| Team Management | Student Statement |
|---------------------------------|--|
| Sharing Prior Experience | Yeah, I also started using Autodesk inventor in high school, and I guess mechatronics is kind of a hobby of mine, so I have a bunch of random things that I play around with. And I'm the design lead for the experiment, so I have some experience there with more cad, and more mechatronics, and team management. |
| Taking Responsibility | This was one of the first projects where I really stepped in and uh, I kind of assumed a leadership role |

| | |
|--------------------------|---|
| Motivating Others | I told them on numerous occasions, “I don’t care how thick it is or how fast it prints, we haven’t flown these before, I want it to be able to fly at high speed into a wall and bounce off like nothing happened. Because if it breaks, we’re done.” |
| Oversight | I definitely assumed a leadership role.... I’m going to say my personal improvement above anything else had nothing to do with engineering but with project management, looking at the timeframes and figuring out what needs to get done by when. |

Discussion and Implications

Engineering education efforts have largely concentrated on improving the technical skills of students. However, recent studies have argued for a more multidimensional view that emphasizes understanding how students view their own learning (Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008). Students are now seen as more directly engaged in the design of their learning trajectories and often follow “unofficial routes” (Stevens et al., 2008). Therefore, it is important to investigate the “unofficial routes” engineering students might traverse to understand the various contexts of engineering students’ learning experiences (Stevens et al, 2008) for the purposes of holistically accounting for situated learning within the engineering landscape (Johri, Olds & O’Connor, 2014). The IAM3D competition provided an avenue to examine students’ experience of an “unofficial route.”

One opportunity that non-curricular groups or programs offer students is navigational flexibility (Stevens et al., 2008). Stevens et al. (2008) assert that each student chooses a unique route through engineering education. Their study also claims that students differentiate between “official routes” and “unofficial routes”, as well as “unofficial strategies” through the official routes (p. 361). For Stevens et al. (2008), navigational flexibility referred to the educational routes students followed in order to demonstrate successful acquisition of accountable disciplinary knowledge (i.e. “actions that when performed are counted as engineering knowledge”, p. 357). According to Kusano and Johri (2014), navigational flexibility is supported by a growing sense of student autonomy. The engineering competition in this study provided students with an unofficial route to gain specific professional competencies.

The results of this study also identified elements in which students engage when they follow “official routes.” According to Stevens et al. (2008), official routes are sanctioned via institutional curricular requirements. Three milestones mark students’ progress 1) goals/interests, 2) horizons of observation, and 3) critical transitions through obligatory passage points. Goals/interests refer to when students “identify their goals/interests and intentionally pursue some educational experience to address these goals/interests” (p. 361). Horizons of observation refer to students developing ‘an understanding of possible futures and increasingly identify themselves with these futures” (p. 363). The self-reflection and future planning findings in this study were similar to the goals/interests and horizons of observation. The differences between the proposed framework and the Stevens et al. (2008) framework is in terms of how students perceived these issues. The Stevens et al. (2008) framework focused on the entire navigated pathway. The students in this study seemed to identify the “waypoints” along the path. Findings from this study showed that students who participated in competitions engaged in “navigational flexibility” and engaged in a holistic application of knowledge and skills within the context of working on authentic engineering tasks.

A key outcome of this research is a Framework of Professional Responsibilities to consider how future research can examine student cognitions, behaviors, and dispositions

about professional and ethical responsibilities. Components of the proposed framework have been previously described in the engineering education literature. For example, Gilbuena et al. (2015) described project management and timeline development as developed within a capstone project. However, the students' discussion of professional and ethical responsibilities aligned most closely with Besterfield-Sacre et al.'s list of professional traits. Specifically, we identified self-management, task management, and team management as the key components of students' experience of professional responsibility within an engineering competition. The development of these components of professional responsibility may be the key to how competitions or service learning may extend project- and problem-based curricular learning. Project-based learning supported the development of understanding project goals and the relationship to project outcomes (Atadero, Rambo-Hernandez, & Balgopal, 2015). Engineering competitions may provide a more intense experience than classroom projects that contributed to the more sophisticated nuances discussed by students in this study. This is not to say that project-based learning is not important. On the contrary, this study provides evidence that a continuum of learning opportunities increasing in levels of approximation to the workplace are critical. Further, it is important to note that although ABET (2013) collapses professional and ethical skills into a single category, our empirical evidence suggests that they might be thought of as more distinct ideas in practice, or may demonstrate how students' develop understanding of the responsibilities.

Components of the Framework of Professional Responsibilities can also be found within similarities to Zimmerman's (2000) model of self-regulation, including goal-setting, task analysis and help-seeking. We distinguished two components of self-reflection, one that focused on task performance, self-evaluation, and one that focused on learning from the competition in a holistic perspective, self-reflection. The distinction between self-evaluation as a micro-level skill and self-reflection as a macro-level skill is important because students recognized that examination of the development process of development was integral to improving product quality, as well as, enhanced the quality of their learning and supported their development as a professional. Further, while elements of Zimmerman's model were present, the students did not describe a cyclical process. Rather, for many students, the self-regulatory behaviors seemed to be "discovered" and acquired as they needed to succeed in the competition and to continue to manage curricular requirements. We also identified several professional responsibilities similar to common features across theories of self-regulation and metacognition, including proactive learning behaviors, strategy selection, and learning process monitoring (Zimmerman, 2001), understanding tasks (Green, Hutchison, Costa, & Crompton, 2012), and processes and responsive actions (Winne & Azevedo, 2014). Thus, in engineering competitions and other types of informal learning or unofficial routes, the cognitions, behaviors, and dispositions engaged as professional skills are acquired appears to require use of both self-regulated learning and metacognitive skills. Future research in engineering education could examine both constructs in more depth.

We also found that students spoke more about their emerging professional skills than the technical skills they acquired or honed in the competition. This finding is consistent with prior research examining service learning (Carberry, et al., 2013). We found that competitions created a context where student concerns focused on demonstrating professional responsibilities in order to help themselves, accomplish a task, or lead their teams. Students developed the professional responsibilities to "rise to the occasion." Gilbuena et al. (2015) found that faculty and student discourse about professional skills was intertwined with discourse about technical skills. We also found that student comments about professional and technical skills were similarly connected, especially in the task management category. However, the interconnections between technical and professional skills were also discussed

more broadly in terms of the competition or engineering in general. Thus, developing understanding of professional and ethical responsibilities is intricately linked to understanding and applying technical knowledge and skills.

An implication of this research for faculty and students engaging in engineering competitions or other informal learning environments in engineering, such as service learning, is identifying the balance between the degree of scaffolding provided by faculty about self-management, task management, and team management and maintaining the authentic nature of an ill-structured problem. Providing scaffolding for general planning and task management processes may enable transfer of such skills to the workplace and represents an important area for future study. An implication for industry is the recognition that assimilation to workplace culture is important in order for students to transfer learning of professional responsibilities, in alignment with research about theories of situated learning (Johri & Olds, 2011). Transfer of self-management, task-management, and team management behaviors across formal and informal learning opportunities and then to the workplace are empirical questions for future research. Future research could be conducted to determine the relationship between autonomy, self-regulation, and the development of professional skills, as well as, judgment and decision-making. Future research might also address how the development of each supports the development of leadership skills within engineering. Finally, future research could include use of the professional responsibility framework to examine and assess the development of professional responsibilities and acquisition of professional competencies in engineering students in curricular and non-curricular activities.

A limitation of the study was due to participant bias. Students voluntarily participated in the competition and, then, in the focus groups. It is possible that the participants in this competition had different characteristics than non-participants. Further, participants in the study may have had very different experiences than those students who chose not to participate. Another limitation is that the study was situated within a specific set of circumstances. Thus, these findings may not be generalizable.

Conclusion

Engineering competitions provide an opportunity to develop professional responsibility and integrate professional responsibility with technical knowledge and skills. The findings in this study support prior research that students' learning in informal environments, specifically competitions, is critical to prepare students for the work environment, specifically as related to managing teams, tasks, and themselves. The findings also extended previous work indicating that student responses about the ABET student outcome, "understanding professional and ethical responsibilities," focused on how to think like, act as, and be an engineer. Our framework spans newly proposed ABET standards (2016) 5 (recognize professional and ethical responsibilities and make informed judgments) and 7 (establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty (constraint analysis)). The findings in this study and the framework add to the extant literature about the benefits of engineering competitions to help students learn professional skills.

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