Entering the Community of Practice: Changes in Engineering Students' Engineering Identities and Perceptions of the Field

Abstract

Policymakers and industry representatives have called for an increase in the number of engineering graduates, but many students, even in their final year of their programs, remain unsure of their plans to enter engineering as a career. The research question guiding this study is: how do changes in students' perceptions of the field of engineering relate to how they describe their development of engineering identity? To address this question, focus group interviews were conducted with 62 students across 15 engineering majors and three universities in the United States. Results indicate that students find engineering to be broader than anticipated, which implicates how they imagine they might contribute to the field. Perseverance, collaboration, and opportunities for authentic engagement with practice lead to success in engineering, and lifelong learning remains important given the dynamic and complex nature of the engineering field.

Introduction

National reports across Europe, the United States, and other parts of the world implore the necessity to increase the number and diversity of students graduating in engineering to meet some of society's most pressing needs (Prieto, Holbrook et al. 2009). However, a high proportion of engineering seniors remain undecided regarding entering the engineering workforce (Lichtenstein, Loshbaugh et al. 2009). Engineering programs have thus been challenged to better understand what shapes students' commitments to an engineering degree to help identify methods to support student persistence to an engineering bachelor's degree.

One explanation put forth over the past decade is that a sense of engineering identity underlies students' commitment to the engineering profession. Engineering identity presents a useful construct for understanding how students view themselves, are viewed by others, and view their role in society (Godwin, Potvin et al. 2013). It also opens avenues to explore other issues related to participation in engineering, such as racial or gender differences in participation (Faulkner 2007, Cross and Paretti 2012). Students who experience further development of their engineering identities are more likely to persist in their degree programs (Matusovich, Streveler et al. 2010, Redacted for Blind Review 2019).

Many studies on engineering identity use the communities of practice model as a framework. This framework is appropriate since engineering education fits the definition of situated learning (Du 2006, Tonso 2016). This model assumes that students learn the skills and knowledge needed to succeed in engineering practice while situated within that practice, acculturating to the culture of engineering in the process. This allows them to construct meaning about what it means to be an engineer in the learning process. What the burgeoning engineering identity literature has not explored in as much depth is the relationship between students' sense of engineering identity development and the meaning they are making about the practice of engineering. Students' perceptions of engineering before college tend to be quite different from their perceptions after entering an engineering program, especially since people outside the field of engineering may not fully understand what engineers do. This study aims to address this gap.

The purpose this study is to explore the relationship between students' engineering identity development and changes in their perceptions of the engineering field from before college to after entering their engineering programs. This study seeks to answer the following research question: How do changes in students' perceptions of the field of engineering after entering college relate to how they describe their development of engineering identity?

Theoretical framework

Engineering education, like other forms of professional education, serves two purposes simultaneously. First, it must meet the standards of a degree established by the academy, influenced by accreditation requirements (Shulman 2005). Second, it must meet the needs set by the profession. As such, one primary goal of the undergraduate professional preparation of undergraduate engineering students is to induct them into the ways of thinking, performing, and acting with integrity as an engineer. This outcome is accomplished through a scaffolded process of engaging students with engineering practice in an increasingly authentic, progressive manner. This process includes experiences such as problem-based learning and typically culminates in capstone projects, and internship or cooperative education experiences.

In so doing, engineering programs provide students an opportunity for legitimate peripheral participation in the community of practice of professional engineers (Lave and Wenger 1991). Engineering education is thus situative in nature, which assumes knowledge to be embedded within a particular physical and social environment, and learning to occur through participation in meaningful activities within that environment (Johri, Olds et al. 2014). The situativity of engineering education can be observed through three elements of engineering education, namely, the use of representations to convey technical information, close association between education and professional practice, and the centrality of design to both engineering education and practice (Johri, Olds et al. 2014). We focus on the association between education and professional practice in this study by demonstrating the interplay between identity formation and constructing meaning of the engineering field more broadly. Legitimate peripheral participation in engineering practice invites students into the discourses of engineering in a manner that initiates them toward becoming full members of said community and ultimately identifiable as practicing engineers (Lave and Wenger 1991, Gee 1992). Through participation in engineering practice, engineering students come to understand what it means to practice engineering.

The development of engineering identity

Engineering identity, for purposes of this study, is conceptualized in alignment with perspectives that examine this process as fundamental to assuming the professional role of "engineer" in the future (Godwin, Potvin et al. 2013). Engineering students are engaged in a professional formation process toward becoming practicing engineers, and through their education they have experiences which provide increasingly authentic participation in engineering practice. Engineering identity is thus developed as an individual makes meaning of these experiences within the context of their construction of what it means to practice engineering, thereby evaluating their identification with the field. Further, engineering identity development can be characterized as a psychosocial process, meaning that it reflects a more complex understanding of self in relation to others, and can be observed through an increase in commitment to widely shared values and worldviews guiding the profession (Meyers 2009).

Yet what it means to practice engineering has long been contested and up for debate (Riley 2008). Furthermore, on a global basis, much of society outside the field of engineering has a minimal or incorrect understanding of the profession (Wraige 2003, Sochacka, Walther et al. 2014). Practicing engineers themselves will point to examples of people doing work their engineering degree prepared them for, but not holding the title "engineer," and of people doing work that did not require an engineering degree but comes with the title "engineer." Some specific fields within engineering are more concretely circumscribed. For example, civil and electrical engineering activities are often highly regulated, leading to more robust gateways into these professions. Others, such as computer and software engineering, are much newer and are still in an active process of professionalization. Thus, given how diffuse the field of “engineering” is, it's no surprise then that one of the most important common contributors to engineering identity is knowing an engineer before entering an engineering program (Pierrakos, Beam et al. 2009), most often a parent or relative. Yet even these students tend to have a narrow view of the engineering profession, flavored by the specific field in which their mentor works.

As a result, engineering students construct what it means to practice engineering while they progress through their academic programs (Danielak, Gupta et al. 2014). Through that process, they also begin to develop a sense of engineering identity as they come to understand their individual position relative to their understanding of what engineering practice means (Meyers, Ohland et al. 2012). One study of first-year students in engineering found participants tended to define engineering in a manner that coheres with their professional goals for pursuing engineering (Lakin, Wittig et al. 2020). However, students in this study who defined engineering as applied math/science or as a method for helping others were less likely to identify as engineers than peers who defined engineering as a design process or solving problems. Through recognition of specific activities as within the domain of engineering practice, their engagement in these activities reinforces their understanding that they are successfully becoming engineers (Godwin, Potvin et al. 2016). Students' mastery of the technical knowledge requisite for doing engineering work increases their confidence in their aspirations to become engineers, and requisite recognition by their engineering faculty that they are mastering this material, through passing engineering courses, is also information used as part of their self-assessment. For this reason a leading instrument for measuring engineering identity conceptualizes two aspects of engineering identity within the same domain: competence/performance (Godwin, Potvin et al. 2016). Through performance, students demonstrate competence of engineering technical knowledge. Students even sometimes defiantly identify as engineers as they persist through setbacks and even failure within their coursework, as they come to realize that engineering work does not resemble the work they are expected to perform in the course of professional practice (Eris, Chachra et al. 2010).

As such, engineering identity may be most effectively fostered through opportunities for authentic engagement with engineering practice. The most common experience students have that provide them the opportunity to directly engage in engineering practice is through an internship or cooperative educational experience (Zehr and Korte 2020). Performing engineering tasks as an intern or in a co-op not only provides students an opportunity to "try out" the work they will perform in their intended careers, it also helps students form relationships with practicing engineers and develop peer networks (Rouvrais, Remaud et al. 2018). Instead of only hearing about what it means to practice engineering from their faculty, many of whom have never worked as a practicing engineer (Dahle, Schell et al. 2018), or other mentors, who may only be aware of one narrow slice of the engineering profession, students can interact with a number of engineers across and within industry settings, all of whom contribute to students' expanding meaning-making regarding engineering practice. Successful performance in an internship or co-op setting can also increase individual students' confidence in their ability to do engineering work and thereby increase their self-recognition as an engineer (Jaime, Olarte et al. 2020), and in turn productive engagement in engineering practice increases the likelihood of being recognized as an engineer by people who are employed as engineers.

Internships and co-operative educational experiences are especially important to engineering students who do not have access to mentors in the field of engineering before college. This would be especially true for engineering students from groups most underrepresented in engineering, Black, Latinx, and Indigenous students, who come from communities that have experienced historic systemic exclusion from the field of engineering (Martin, Simmons et al. 2013, Skvoretz, Kersaint et al. 2019). In addition to interactions with mentors and colleagues through internship and cooperative educational experiences, these underrepresented students and others can benefit from meaningful interactions with mentors and advisors who can help them make sense of what they can accomplish as a practicing engineer (Dika, Pando et al. 2018). These interactions are often facilitated through cocurricular engineering activities, especially clubs and organizations that either organize around preparation for entering a specific field of engineering or around building community among students with a shared set of experiences (Hinkle and Koretsky 2018). Organizations that address the needs of minoritized students in engineering, like the American Indian Science and Engineering Society or oSTEM (Out in Science, Technology, Engineering, and Mathematics, focused on LGBTQ students), help students find a sense of community and connect with mentors who can also speak to some of the unique barriers these students face in becoming engineers (Chang, Sharkness et al. 2014). Cocurricular engineering opportunities do not consistently predict greater degrees of engineering identity in the literature (Meyers, Silliman et al. 2012), but this lack of consistency does not mean these experiences make no difference for individual students. What seems to matter most, though, across all these factors that have been shown to relate to engineering identity, is the cultivation of self-recognition as engineer, and recognition by meaningful others who have some authority with respect to engineering practice.

Methods and Materials

To achieve the purpose of this study, we employed a qualitative grounded theory approach (Creswell 2013). Grounded theory is a qualitative approach intended to construct a theory "grounded" in data collected in the field (Glaser and Strauss 1967). The data for this study are taken from a larger study developing a grounded theory explaining how engineering leadership identity is developed. The broader project conceptualizes engineering leadership identity as reflecting an aspect of self that emerges from the intersection of engineering and leadership identities but is also an aspect of self qualitatively different from these two aspects of identity. As such, one focus for data collection is the development of engineering identity situated within an undergraduate engineering program. This is the data utilized in the study presented here. The protocols for this study were reviewed and approved by the [university 1] Institutional Review Board, IRB #WS120418-EX.

Data collection

Participants for this study were undergraduate engineering majors at three universities in the United States. These three universities were selected to represent a range of institutional settings with regard to diversity of participants and diversity of their experiences. The three universities were [university 1], which has been recognized for its commitment to serving American Indian students, [university 2], ranked among the top 30 engineering programs in the United States, and the [university 3], a Hispanic-serving institution in an urban setting with a large proportion of commuter students. Across these three institutions, 62 students participated in this study, representing 15 different engineering majors. Slightly more than three-quarters of these students were upper division students. See Figure 1 for participant demographics.

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Data were collected through focus groups with participants on each campus between November 2018 and June 2019. In total, 20 focus group interviews were conducted on topics pertaining to students' perceptions of components of identity development. The interview protocols were divided into three parts to ask students about their engineering identity development, their leadership identity development, and their engineering leadership identity development. Interview questions focused on engineering identity included, "Do you consider yourself to be an engineer? Why or why not?", "How do you think one becomes an engineer?", and "Has your understanding of what an engineer does changed? What experience (events or people) led to that change?" Focus groups lasted approximately one hour, and refreshments were provided. Prior to participation, interviewers provided informed consent forms to all participants; explained participants' rights, risks, and benefits; collected a signed form from each participant; and provided a copy of the form to participants to keep.

Data analysis

Focus group interviews were digitally recorded, and a third-party transcription service was hired to transcribe interview recordings verbatim. These transcripts were reviewed and cleaned by members of the research team to ensure accuracy and completeness. Transcriptions were then open coded by the team to determine an initial codebook to apply to interview transcripts (Strauss and Corbin 1990). The open coding process started with the selection of a transcript, followed by all seven members of the research team reading the transcript and writing memos and margin notes individually, then meeting as a team to review these notes and develop a list of potential codes, culminating in the selection of a new transcript and iterating the process.

After reviewing four transcripts, a set of twelve broad codes were identified for the first round of coding and subsequently applied to the transcripts using Nvivo qualitative software, version 12. The two broad areas considered in this work were 1) changes in students' perceptions of the field of engineering and 2) development of engineering identity. Members of the team then subcoded these broad areas to add nuance and detail to the coding of data within the broader categories (Saldaña 2013). Subcoding was accomplished through pairs of team members working together to read text coded in the first round and identify subcodes within that text. Team members worked together using two transcripts to identify the list of subcodes, worked with a third team member on a third transcript to confirm the list of subcodes, and then finished coding the remaining transcripts. Subcodes were then analyzed using focused and axial coding to connect and categorize subcodes within and across the broader codes, and theoretical coding was used to structure the findings and develop themes and propositions.

Trustworthiness

Trustworthiness is the standard to assess the quality of a qualitative study with respect to the rigor of its design (Patton 2015). Attention to trustworthiness includes consistency, credibility, and transferability. Credibility was ensured through the development of research protocols through engagement with the literature, pilot-testing with people who met the research criteria, review of protocols by outside evaluators, and presentation of representative pieces of data. Consistency was ensured through maintenance of a data base and audit trail within the Nvivo software platform as well as involvement of multiple members of the research team at all stages of data collection and analysis including full team discussions of codes and emerging findings. Transferability, the qualitative counterpart to generalizability, was ensured through recruiting a diverse set of participants across a range of institutional settings and the use of "thick description" in the presentation of research findings.

Findings

The purpose of this study is to explore how students' experiences in their undergraduate engineering programs changed their perceptions of the field of engineering and thereby shaped their engineering identity development. Overall, gaining a sense of what engineering practice was really like deepened students' interest and increased their confidence in practice. Increased interest and confidence were associated with a stronger sense of engineering identity, though most participants were still reluctant to consider themselves "engineers" without the requisite external markers (e.g., engineering degree, FE exam, licensure). The process is a bit more complex, though, than simply authentic engagement in engineering practice leading to stronger engineering identity. The findings from this study uncovered a richer context in which engineering identity development takes place. Entering an engineering program broadens students' perceptions of the field of engineering in many ways, which causes them to understand their position within the field to be quite narrow. As each practicing engineer holds a similarly narrow place in the field, collaboration is essential to tackle the complex, ill-structured problems that characterize engineering practice. The process of becoming an engineer is generally understood as a linear process with discernible milestones along the way, but the process is also open-ended in that one will always find opportunities to improve in practice, even after many years of experience. Figure 2 presents a graphical summary of the study findings.

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Becoming an engineer

Unsurprisingly, completing an undergraduate engineering program is one of several discernible milestones students identified on a generally linear path toward becoming an engineer, as one participant succinctly stated, “Graduating. Getting a job. What not. The next step.” Within their undergraduate programs, students described a sort of timeline from college entry through graduation along which they encounter a generally uniform set of experiences that position them for their post-graduation job search. As such, students described their progress toward a degree in relative terms: “I'm a sophomore right now, so I have a whole lot of professional courses left…. In the meantime, if some professors give me a research opportunity, then I will take advantage of it.” These experiences included their prescribed sequence of courses, cocurricular opportunities, and internship opportunities.

As a result of being able to “measure” their progress toward an engineering degree in such explicit terms, participants were reluctant to recognize themselves as engineers. One participant explained, “In these four years…, there's a lot of growth that happens…. I have a little bit more experience that I need to gain and bases that I need to learn before I can claim to be an engineer.” That said, engineering identity was not discerned solely on the basis of these external markers of progress toward a degree. Underlying these steps toward an engineering degree was an internal process of the development of an engineering mindset, or learning how to think like an engineer:

> I will consider myself an engineer once I get to that goal where … if any project that I can think of, if I can figure out how to do it and actually accomplish it, at that point I would be an engineer, in my mind.

In other words, students recognize that as they make progress toward their degrees and gain experience in engineering practice, their approaches to engineering work begin to more closely resemble those of practicing engineers—they begin to think like engineers.

Developing an engineering mindset increases students’ confidence in doing engineering work, which leads them to a greater willingness to consider themselves as engineers. “When I started, I had zero confidence in myself; I was really nervous about everything I did,” one participant described:

> As I got through engineering, each problem I solved, each complex thing that I started with and had literally no idea how to start solving, as I would begin to figure out bits and pieces and break it up into many small pieces, and then overcome those challenges, I think I started to become an engineer, which was someone that looks at a problem, is not afraid of it, breaks it down, and build[s] a solution out of it with other people.

This participant recognized they were starting to look at engineering problems the way an engineer might. One student used the neologism "preten-gineer" to capture how they experienced engineering identity: “It's kind of just…a student, and you think like an engineer and you're in engineer [sic] classes, but you aren't an engineer yet.” “Preten-gineer” gave this student a term that identified them with the engineering profession that did not make too strong a claim about their ability and experience.

Although participants themselves may have been reluctant to consider themselves engineers, several pointed out that other students call them "engineers." One participant made a comparison to another professional field:

> In undergraduate, people are like, 'Oh, he's an engineer,' even though I'm like a sophomore or junior in engineering, really don't know what you're doing at all. Versus like a medical student, you don't consider anyone a doctor until they have an M.D. Like, a pre-med student is not a doctor.

Perhaps undergraduate programs provide a setting for anticipatory professional socialization, but to this participant the disconnect between their internal experience and the perceptions of their peers provided an important opportunity for reflection on his own engineering identity development.

Further, participants pointed out that, in many (if not most) cases, after earning their degrees they will need to take their FE exam and work for several years as an Engineer-in-Training before being able to claim the professional mantle of "engineer," extending their view of a linear timeline into the profession. Several pointed out, when prompted to describe the "ideal engineer," that this concept represented the ultimate endpoint of these timelines: a state they would never reach, but to which they desired to continuously improve. As a result, participants generally felt lifelong learning and improvement was endemic to an engineering career.

Being "groomed for engineering"

As in many previous studies, this study found that experiences students had before college shaped their engineering identities. Several mentioned having known engineers before college who helped "demystify" the engineering profession in ways which aided them in clarifying their career goals. As one participant put it, "I talked to some guys at my dad's work who do a lot of engineering, design stuff … actually talking to people who currently work in engineering and being like, 'Oh, this is what happens.'" Knowing an engineer before college, especially having an engineer for a parent, can be an important first step in developing an engineering identity.

Not every student has this experience, however, as one participant pointed out: "I feel like a lot of people are pretty well groomed into engineering. They're strong in high school in math and science and stuff like that. They can get through most of the gatekeeping that guards the profession." They raised this conventional path when asked about characteristics of an "ideal" engineer, suggesting a great deal of privilege is structured into the engineering preparation process, even before college. The preparation process is uneven—some students are encouraged or even pushed by their parents to take the requisite steps to prepare to enter an engineering major, such as advanced math and science in high school, which then predict a higher likelihood of completing an engineering degree and entering the field. That said, this participant reframed his unconventional pathway into engineering as an asset because he had worked as a technician previously and now can relate to technicians with whom he might work as an engineer.

Broader view of engineering

After entering an undergraduate engineering program, students receive a "peek behind the curtain" of the field of engineering: "I think that the scope of what people think engineers do versus what they really do is a lot different from the inside of the box." Specifically, being in an engineering program expands students' perceptions of the field in many ways, including introducing them to new fields within engineering, like industrial and financial engineering, as specified by one participant. Another participant noted, "Different types of engineering, and then like specializing—like within civil, you can specialize in like five different things, and focus in all those categories. Or you can go on to do something not related to engineering with your engineering degree." The world of engineering was far more multifaceted than participants thought prior to entering college.

Another way participants' views of engineering were broadened was through incorporating skills and knowledge previously seen as "not engineering" as essential to engineering practice. One participant observed:

> There's a lot more than the surface, too, of just design…. Now I have a much better grasp, too, that there is analysis, there's design, there's estimating and bidding, there's so many different parts of engineering that I had no clue the scope of. And now that I'm in it I have a better grasp of that scope but sometimes it feels like even bigger.

Several participants commented that they were surprised how important management and interpersonal skills were to accomplishing engineering work. Upon reflection, though, these participants felt given how much engineering work is necessarily accomplished in teams, this observation should not have been a surprise.

Students' sense of engineering identity is implicated by this broadening of their perspective because they recognize how narrow their own contributions, or indeed of any individual engineer, to the field will be. As one participant put it, "The moment where you see how broad and how big the profession can be is whenever you see... really good engineering…and obviously it's a bunch of people, and they're very, very good at their jobs." Further, it's likely that recognizing the breadth of the field, and the "smallness" of their individual contributions, contributes to students' reluctance to identify as engineers: "I am starting to realize how much it is going to take and how much more effort that I am going to have to put in to get where I want to be." One student expressed, "You learn more, and then you learn more about what you don't know. So, you're like, 'Sigh…'" while another found:

> I thought of like it being like these grand tasks that a couple people would take on. And then actually getting into engineering, I just realized like it's a huge system. There're so many pieces of that puzzle, and that engineers have just, they all take a small sliver. So, it wasn't as daunting when I actually got into it.

Gaining a broader view of the field may be intimidating at first, but working through an engineering program can help an individual rise to the challenge and start to find their place in the field.

Engineering is persevering through failure

Broadening students' views of the engineering field is important for their professional formation. The process influences their engineering identity development in unintended, positive ways. One of the most significant ways is the development of perseverance needed to master the breadth and rigor of topics required for an engineering degree, as one student noted: "You take such different types of classes that most people that I know have some classes that they really don't like…. I'm just going to like put my head down and like power through." This student indicated that by situating this one class within their broader goal of becoming an engineer, the task at hand becomes much more bearable to endure.

Students also experience the breadth of the field through tackling the ill-structured problems characteristic of engineering. As indicated earlier, students found that seeing all that encompasses engineering means they learn what they do not know through approaching novel problems. As such, developing an engineering mindset necessitates cultivating the persistence needed to persevere in the face of failure as a result of trial and error in developing a solution:

> If someone is driven enough to put themselves through engineering, then they can be an engineer too even if they are not naturally inclined…. It takes someone who is driven to be able to sit there for longer than expected or longer than usual and try to solve that out, because that is the kind of characteristics in engineers to like change something.

More than one participant spoke about the need to work through a problem several times before reaching a solution that worked out. In fact, one felt it was important to be willing to fail to become an engineer.

Developing a problem-solving mindset, self-directed learning skills, and perseverance then all build confidence, which contributes to recognizing oneself as an engineer. One student, looking forward, stated, "When I am able to feel confident in my problem-solving skills is when I am going to be stoked and proud to call myself an engineer." Another captured feeling like a "preten-gineer" in discussing their confidence, "[I'm] still kind of building that confidence, right, to ask questions and figure out how to be an independent engineer, instead of just being like, 'Hi, I think I learned this once in dynamics and I don't know what's going on.'"

Breadth of engineering necessitates collaboration

Understanding the breadth of the engineering field also demonstrates to students the importance of interacting and collaborating with their peers. One participant summed up, "It's the collaborative group effort, and then the sheer determination to get through it, for me, are the two primary pillars of what makes an engineer." Primarily, participants recognized that engineering tasks require bringing together people with differing expertise to help overcome the limitations of their individual knowledge: "What I really learned from this point, and especially this semester taking a design seminar, was that [engineering] is very multidisciplinary…you have to come together and figure out, 'Hey, this is how we can put [the project] together.'" Each person contains the skills and knowledge to tackle one aspect of a project, but the whole of the project requires the expertise of many people to accomplish.

Working with their peers also helps increase students' engagement with the field in ways that likely sustain, or even increase, their commitment to engineering. "You realize that there are so many other people that want to do the same things that you can…I definitely have found a lot of people who shared my enthusiasm." One participant noted that working together on homework or class projects provides essential support for tackling difficult coursework:

> A couple of my friends that I've been in classes with, they prefer to study by themselves, which is totally respectful. But then after the test, when they're, 'Oh I didn't do as well.' 'Oh, you know, study with us next time.' And then they do, and their test score improves.

Engineering coursework is characteristically challenging and rigorous, so engineering students have long found working together helps sustain their aspirations to enter the field and persistence to complete their degrees.

Interacting with their peers is also critical for addressing one of the chief professional concerns raised by participants, securing employment in engineering after college. Fellow classmates become a crucial part of one's professional network to find job opportunities and professional recommendations. One participant noted, "It's also good to make connections, because I have a lot of friends who are in the securities, the security industry, cyber security, and anytime one of them is looking for a job, they just go, 'Is anybody hiring?'" These kinds of professional networks consisting of weak and strong ties have long been known to aid in the process of finding resources (Granovetter 1977).

Authentic engagement in practice affected view of engineering

In discussing changes in their perception of engineering, students' examples pointed to settings where they were more likely to experience these shifts. Settings that most influenced student's perceptions of the engineering profession were also settings where students were able to apply engineering knowledge to real-world problems. The most obvious of these locations were internships, but cocurricular activities and the classroom were other important sites. One student described their insight into how faculty structure class projects to foster deeper learning: "They know that we have no knowledge of these higher-level things, and we're expected to pick pretty advanced projects. So, we're kind of pushed into learning a lot of advanced material in a small amount of time." Faculty are able to organize the class setting in a manner that simulates engineering practice, fostering the development of an engineering mindset as described by students earlier (perseverance, self-directed learning, and problem-solving skills).

Learning how to grapple with ill-defined problems then was most helpful in preparing students to engage in real-world engineering practice, especially in dealing with clients. One participant explained that raising the stakes improves the outcomes students achieve: "I applied for this space grant position, this whole program that we have here, and I got in. We actually have like a real client, and he is actually asking for a product to make, so if we actually fail like it has real world consequences." Not only is this student working on a real-world problem that does not come with a clear-cut solution, this student is involved with dealing with a client who has a stake in the outcome of the project. This experience also reinforced the importance of collaboration, but this time in a setting beyond one's peers.

Real-world experiences then build students' confidence in doing engineering work, building their sense of engineering identity. One participant described:

> As you grow in confidence as you learn how to approach problems, I would say the huge next thing is then to be applying the knowledge…. It wasn't until I took like an internship and was actually building something that I began to learn like what, what everything I learned mean.

For these reasons, participants nearly universally placed internship experiences as a milestone toward becoming an engineer.

Limitations

The data presented in this study are limited in important ways that a reader should consider when interpreting and transferring study findings. First, although the data represent a wide variety of students and institutional settings, all three institutions are public research universities in the United States. The experiences presented in this paper may differ from those of students at smaller or more teaching-oriented universities and those in other global locations. Second, as participation in the study was voluntary, students who are likely to participate in research may differ from their peers in ways that could bias the results; involvement of undergraduate researchers on the team helped overcome this limitation to some extent by helping to recruit participants who may otherwise have overlooked this opportunity. Third, as the principal investigators are faculty and one of the team members a graduate student, power differences may also have affected how participants responded in focus group interviews. To alleviate this potential problem, all focus groups were facilitated by two team members, at least one of whom was a student (in several cases focus groups were facilitated by two undergraduate researchers), and the engineering faculty team member did not facilitate groups with current or former students.

Discussion and implications

Overall, the purpose of this study was to understand the relationship between students' perceptions of their engineering identity development and their perceptions of the field of engineering, especially how their perceptions of the field changed after entering college. Generally, students' perceptions of the engineering field were broadened by entering an undergraduate engineering program. This implicated their sense of engineering identity development by, in a sense, helping them find a place within that field. Students' experiences also reflected a degree of agency over their ability to find a place within engineering, both in terms of overcoming challenges associated with not being "conventionally prepared" to enter engineering and in terms of rising to the high expectations required to earn a bachelor's degree in engineering.

The data demonstrated that the communities of practice model fits engineering education well (Wenger 1998). This model explains that learners' identities are transformed through engagement with a practice where they negotiate the meaning of that practice within the context of a community that shares that practice. Authentic engagement with engineering was especially influential in shaping the meaning students construct about the field of engineering, which caused them to build confidence and see themselves more as engineers. In addition to internship experiences (Zehr and Korte 2020), many pointed to the work of specific faculty who were establishing these opportunities in the engineering classroom.

As such, an important implication for engineering educators is to consider more intentionally how learning experiences can be designed to provide more authentic engagement with engineering practice. Between working through ill-structured problems, and persevering through failure, activities like problem-based learning can be structured to provide very early, and very peripheral, opportunities to participate in engineering practice. Collaborating with industry partners to design these opportunities would raise their level of authenticity as a simulation of engineering practice. Engineering educators would also do well to consider how internship and cooperative education opportunities could be supported through pedagogical elements modeled as communities of practice. Educators can work with students to reflect on their internship experiences as authentic engagement in practice, and industry partners could work with educators to provide experiences where students' engagement with practice is scaffolded to move from more peripheral to more central participation (Lave and Wenger 1991). This implication transcends the United States context as engineering programs globally, such as in France (Rouvrais, Remaud et al. 2018), seek to assist students with finding these opportunities for legitimate peripheral participation.

Early exposure to engineering was also a salient point for participants in this study, as seen in previous research (Pierrakos, Beam et al. 2009). However, a critical point was raised about precollege engineering experiences that builds onto existing research showing the role these experiences play in shaping pathways into engineering. In addition to systematic differences between students based on their background—in terms of which students may be more likely to be introduced to engineering before college (Strayhorn, Long Iii et al. 2013)—other privileges may be at play such as the transfer of social and cultural capital from practicing engineers to their children to "groom" them for these fields in ways different from their peers. Engineering programs may consider how their recruitment and retention activities might be relying on traditional pathways into engineering by making these capitals more explicit and findings ways to enable students with different forms of capital to enter and succeed in engineering programs.

One key aspect of participants' experiences that supported the development of engineering identity was increasing their confidence in their engineering skills, in alignment with nearly all models for engineering identity development (Godwin, Potvin et al. 2013, Patrick and Borrego 2016, Morelock 2017). Broadening their view of engineering, however, held the potential to shake that confidence by showing just how complex the field of engineering really is. Engineering educators may use this opportunity to help students see their place within the field as becoming more specialized, and more central, as they progress. The engineering formation process is structured in a linear fashion that proceeds from core basic building blocks through completion of real-world engineering problems that, over time, brings learners into engineering by scaffolding their participation in practice. Additionally, students began to recognize the importance of collaboration, which can help bolster their confidence as well. The more intentional and transparent faculty and administrators in engineering programs can be about the professional formation process, the better these programs can support student development of engineering identity.

Finally, between describing how their view of the field of engineering had expanded after entering college, and how their perception of what constituted an "ideal" engineer was a state that most people were unlikely to reach, participants felt lifelong learning and development are essential to be successful engineers. This finding should be encouraging to engineering educators who aspire to develop engineering students who see lifelong learning as an essential value in the field. National reports have argued that lifelong learning is an essential aspect of the engineering profession (Dutta, Patil et al. 2012); engineering programs should capitalize on this finding and make habits for lifelong learning a core outcome of an engineering degree. Additionally, accreditation agencies and boards in Canada, the United States, and other countries hold lifelong learning as an important outcome for students who graduate from accredited engineering programs.

Conclusion

Leaders and policymakers in nations worldwide have called for an increased number of students graduating with engineering degrees in the near future. One path forward to increase engineering degree productivity is to understand how students develop a sense of engineering identity, which has been shown to undergird student motivation for and commitment to entering engineering as a career, as well as highlight barriers to and opportunities for broadening participation among people from groups underrepresented or underserved in the field. This paper looked at the ways students' sense of engineering identity was interrelated with their perceptions of the field of engineering and found the two were inextricably linked. By understanding students' perceptions of the field of engineering, researchers uncover an additional dimension of students' engineering identities that reflects how they position themselves within the broader field of engineering. In so doing, researchers gain a better sense of the deeper values and motivations driving students to enter engineering, which may support efforts to broaden participation through providing new ways to imagine one's contributions through engineering to society.

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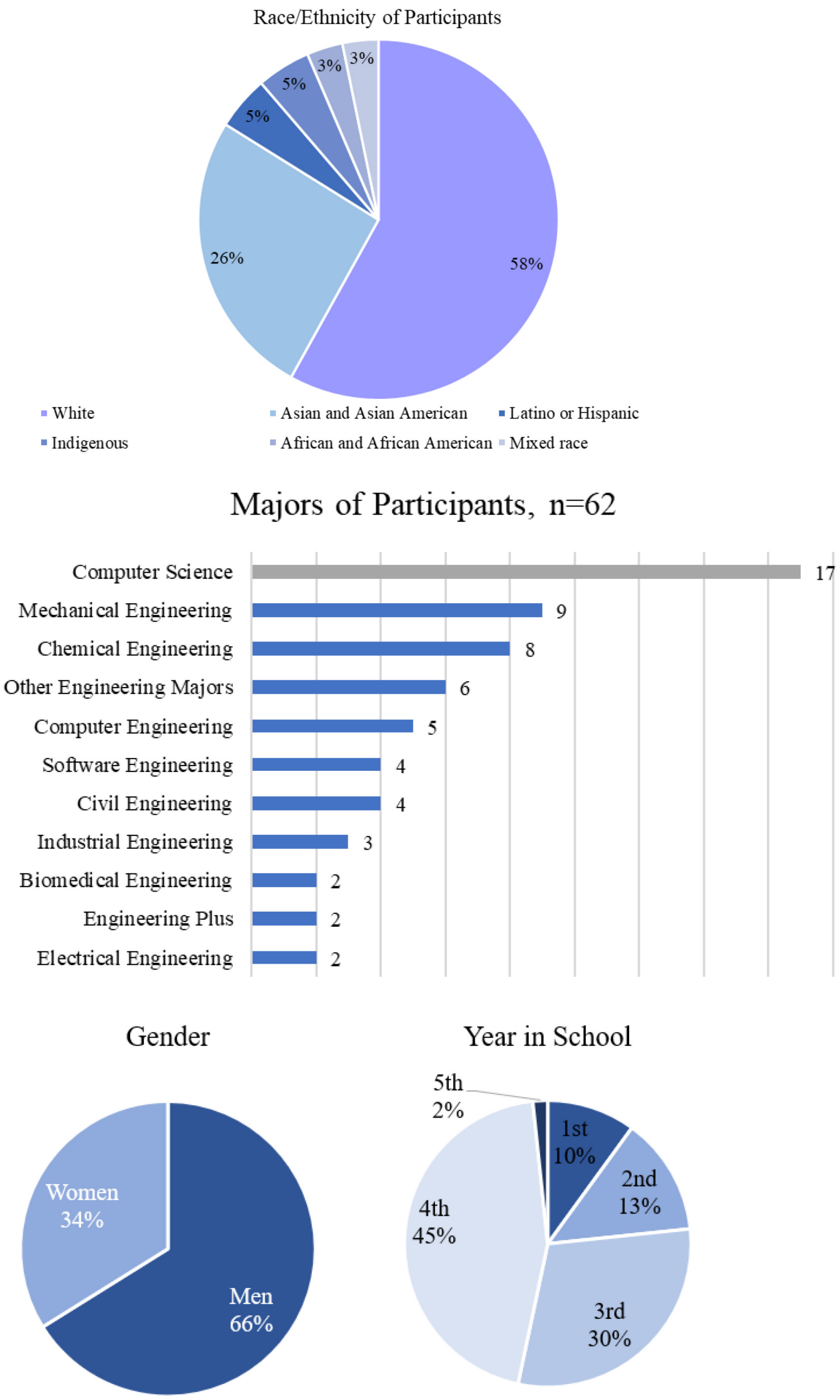

*All participants identified with a binary gender.

Figure 1. Participant demographics.

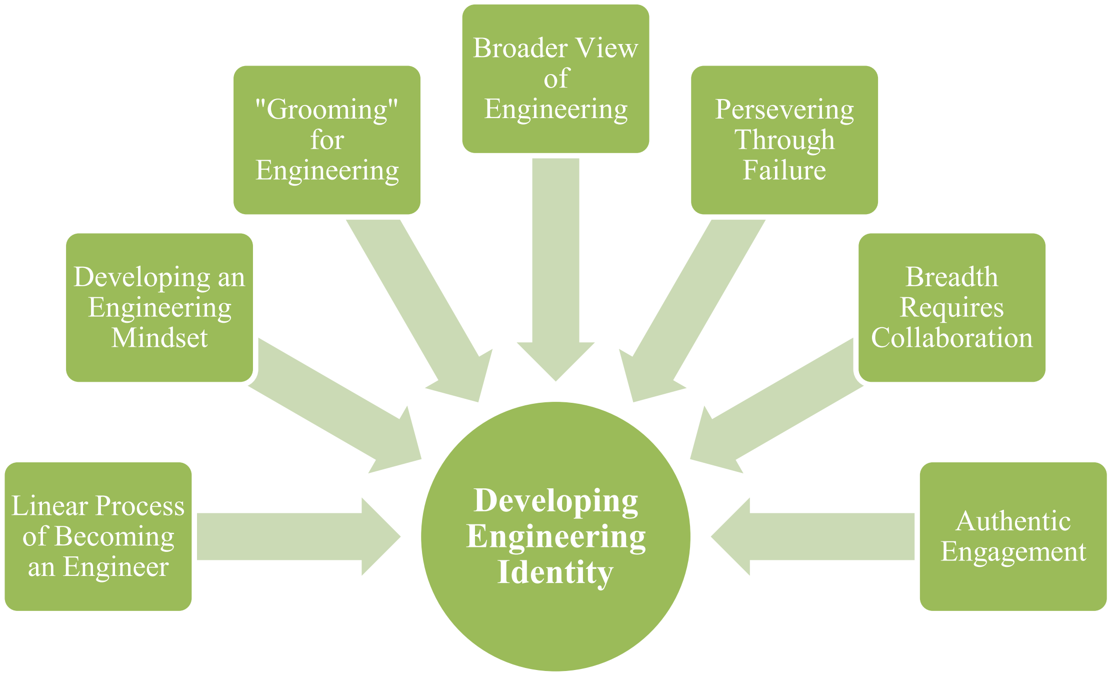

Figure 2. Graphical summary of findings.