A Qualitative Study of Undergraduate Women in Engineering Project Teams

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Abstract

One intervention thought to foster women's interest in engineering is introducing girls to STEM or engineering activities. The argument for this is that an increase in interest early in their lives will lead to more women pursuing a career in engineering. The focus of our research is women who are thriving as undergraduate student leaders in engineering project teams. We employ a multi-case study method that involves a sequence of semi-structured interviews. This paper speaks to the findings derived from the life history interview where participants describe their early lives and pre-college education. Our inductive thematic analysis of the data indicates that: (1) The women's early familial influences allowed non-gender defined ways of being, doing, and aspiring for trying new things. (2) This re/definition of gender in relation to self is reinforced by their success in school and through their accomplishments in other extracurricular activities. Those activities were not confined or even heavily weighted toward STEM. (3) Not all of the women assumed leadership roles throughout their K-12 schooling. Nevertheless, what is common is that through academic and extracurricular engagements they developed confidence, a "can-do" attitude, and a rejection of viewing failures as defining indicators of their ability or potential. Their self-awareness, their confidence, and their persistence in the face of failure are critical because they later function as counter-narratives in the women's encounters with sexism and other forms of marginalization when in engineering and their project teams. Finally, there is some evidence to suggest that encouraging young girls to involve themselves in STEM and/or engineering may be counterproductive. By unintentionally "pushing" these young girls into engineering, rather than "allowing them to choose for themselves," we may be encouraging the adoption of masculinist gendered roles associated with engineering.

Introduction

It is generally accepted as an evidenced proposition that (1) early engagement, elementary through high school, in STEM practices and activities is critically important for encouraging post-secondary and career interest in STEM fields [1-6]. Another generally accepted proposition (2), is that girls and women, similar to other underrepresented groups, face barriers to participation [1]. Moote et al. [7], for example, suggest that "the belief that engineering is for men starts early," perhaps as soon as ten years of age. It is these two propositions that have spurred many to believe we will increase the number of women interested in post-secondary STEM fields through early actions. These actions are engaging girls and young women early in STEM practices and activities and directly challenging the masculinist culture associated with engineering. And through this, we will simply produce more engineers.

However, evidence for the first of these two propositions is not as unambiguous as we might like. Two National Research Council (NRC) reviews offer "limited evidence for many of the benefits predicted or claimed for K-12 engineering education[8], and "not extensive" evidence for early engineering education impacting "achievement, disciplinary knowledge, problem-solving ability, and ability to make connections between [STEM] domains"[9]. Similarly, a survey of over 20,000 Year 6 and 11 students in the UK found "that there is currently little detectable evidence of an impact of …engineering interventions on the

aspirations" of those students to become engineers [7]. If there is limited, or at best not extensive, evidence, perhaps we should study more carefully those women currently enrolled in engineering programs, especially those women who are thriving. What can we learn from listening to them about their early experiences – STEM, engineering or otherwise? And, while it is certainly the case that women do face barriers in engineering; in a survey of students ages 15-18 from 39 different countries, Köycü and de Vrie [10] found that 74% of the males and 81% of the females "clearly indicated that women are just as good as men were in engineering." So, why aren't these barriers coming down? At the same time there's been concerted effort to involve more girls and young women early and often in STEM and engineering. Schools and college of engineering are attempting to make their programs more welcoming. Yet, the aggregate number of women receiving bachelor's degrees in engineering in the US has remained stuck at approximately 20%.

As part of a large study titled, *"We Are Thriving,"* we have been listening to young women tell their stories. Our research focuses on women who are thriving as undergraduate student leaders in engineering project teams. As much as possible in an academic context, project teams simulate authentic engineering practice. There are generally three types of project teams: competition teams, e.g., concrete canoe, ChemE car, service teams, e.g., engineers without borders, and client teams, e.g., app development, data science. We used a sequence of three different types of interviews as our data collection method. This paper speaks to the findings observed from these women participants' pre-college education or what we learned from the first round of these interviews. The study involves three institutions intentionally chosen as each represents distinctive student demographics and institutional types - one public research university in the Midwest (site one, noted as S1), one Ivy League research university in the east (S2), and one designated minority-serving institution in the southwest (S3).

Our research methods follow this brief introduction. Next, the results include the presentation of three themes emerging from those first interviews, followed by a generalized/idealized presentation of each theme, direct quotes from participants at all institutions and a short summary. Finally, we discuss both their relevance to other current research and what our results suggest about how we might consider addressing both the long-standing and frankly alarming failure to attract more women to engineering and how we might support their belonging and becoming engineers.

Methods

This study includes a sequence of three different types of interviews. We received IRB approval at all institutions before recruiting participants. The first interview is their life history and the focus of this paper. It attends to the ways that women in engineering narrate their lives and how they understand themselves to have selected engineering. The second interview, or learning journey, highlights women's journeys through their engineering degrees and focuses on their pathways to and through their different project teams. In the last PhotoVoice interview, we first empower participants to capture meaningful moments of their experiences in their project teams through photos and videos, the ones they regard as important or representative of who they are, as a project team. The participants are asked to provide a caption and a short description for

the photos or videos captured. We then have a final interview where the women participants tell us why they took these photos/videos and what they mean to them [BLINDED].

Each interview was approximately 60 minutes in length and led by a team member at that institution; often a second team member was present in a supporting role to ask follow-up questions. All interviews were conducted over Zoom so they could be recorded and allowed for flexibility with the student schedules, particularly as we started this research during the Covid-19 pandemic. Interviews were then transcribed and coded by the faculty researcher/s at the same institution as the participant. Participant anonymity is ensured as much as possible with pseudonyms and at times, slight changes to the contextual information or timeline to reduce the specificity that could lead to easy identification. We created our original codebook using three participants' data; independent coding and analysis, followed by inter-researcher deliberation and consensus building which allowed us to accomplish the researcher triangulation to help ensure the coding consistency across research sites of the project. The original codebook served to guide our analysis. However, that analysis did not forbid potential new codes or patterns to emerge as we collected our data. When new codes did emerge, they were discussed within our research group. If we decided those new codes were sufficiently significant, they were incorporated. Overall, the initial codebook was found to be applicable and a good fit [BLINDED].

All participants were compensated a $25 gift card for each interview, totaling $100 for participating in the full sequence, including capturing PhotoVoice interviews. We have interviewed 21 participants who are diverse in their fields of engineering as well as their race. Herein, we present the results of the thematic analysis from the first interview, supported by specific examples.

Results and Discussion

The results of our inductive thematic analysis of the data indicate three themes. These themes emerging from the stories of their experiences are important for two reasons: 1) the reported experiences served to affirm that these young women belonged to the engineering community and could become engineers; 2) the experiences also functioned as shields and counter-narratives in the women's encounters with sexism and other forms of marginalization (i.e., the intersected ones) when in engineering education and in project teams. As shown in Figure 1, the themes of improvising, agency, and self-efficacy are interwoven into their path towards thriving in engineering. We offer a simplified explanation of each theme in Figure 1, interpreted by one of the women engineer researchers on this project. A more detailed description of each theme, followed by the idealized case, and exemplar quotes more fully define Figure 1. Each quote is labeled as site number (1,2,3) followed by participant number at that site (i.e., 1-7).

Figure 1. Graphical model of emerging experience themes identified from the life history interview

Theme 1: All of the women participants were aware of gendered ways of being and doing. For some, their earlier familial/parental influences on non-gender defined ways of being and doing allowed them to explore what they were interested in and comfortable with who they were while they were exploring. For others, it was the positive experiences and influences from other people or peers that helped them to develop a sense of self and ignore or reject the essentialization that gendered roles and expectations typically prompt. However, the most important contributing factor was their own "I want and I can," especially when their ways of being and doing seemed contrary to gendered conventions. We refer to these as *experiences of improvising*. Perhaps the most long-lasting impacts of such experiences were to reaffirm that whatever they wanted to do, they could do.

Idealized Case: Cooper has a multiracial background and for her the appropriate role was always understood to be what she was doing or cared to be doing at that time. While she was aware of others' expectations, her own expectations for herself generally prevailed. Indeed, she did not shy away from ignoring, even on occasion defying others' expectations. Cooper was careful to do well enough in school to keep her options open for the future. But she also was constantly on the lookout for pursuing whatever might interest her. Cooper believed that she should try and try hard to do whatever she started and if it didn't work out, she was on to the next thing. There were important successes, small and large, past and present, ample for her to feel satisfied with her choices. Her parents, her teachers and sometimes even her friends did not always approve or understand why she did what she did. Still, Cooper trusted in her experience enough and her eventual understanding of the meaning of that experience for her to persist. She enjoyed being a bit unpredictable.

Exemplary quotes from different participants supporting theme one:

"I saw most of the time I was actually in shorts in this period of my life. It was either like boy's jeans or shorts. I was like super tomboy. And then we all carry pocketknives. And my parents, you know, taught us how to use knives young enough to where they weren't worried about it. My mom could do stitches in the kitchen, if need be. But that was never a thing that

happened, because like they told us how to use knives, because they knew we're interested in it."
[S1P1]

"I said they were both pretty adamant that my brother and I learned how to do things that are, that would be, to use a slightly Victorian term, sort of separate spheres. Um, so, um, I would say that I would say that my parents were both very much against us being told that we couldn't do things because, because I was a girl because he was a boy. And I would say that, perhaps, I just wasn't even exposed to that as much as a number of my peers because it was, it was just very rarely even a question for us about whether we could do something. If we had a question about something we would ask and they would, you know, typically try and find us a way to explore it, which was really cool and really cool." [S1P2]

"I had a few friends that really supported me, but they and my family weren't really too much into computers. They, all of my friends and family came from like medical, so they really supported me in the way they could, but they never really understood what I was doing. They were just there to cheer me on. I 100% got a lot of objections from my parents. They knew that doing work on computers was a good profession, but they were worried that I wouldn't be financially stable in the future, and it was kind of getting over that hurdle too, help like bring them to my side, I guess you could say." [S2P1]

"I think my mom was the most encouraging because her grandfather was an electrical engineer. But I feel like my dad was a little bit different. Now that I am in the field, I guess it's because I have brothers too, so I sometimes feel like, "Why isn't my son doing that?" But he doesn't tell me that directly, so I don't see much support, whereas I get more support from my mom. I don't think my dad's ever told me he was proud or anything. So, my uncle did after, he was like, "This is very good like you're pursuing it." So, I get most of the support from my uncle, brother and my mom. For my dad-I don't very much hear it. It may be indirect, so it's like a little bit different." [S3P1]

Holland et al. [11] introduce an important concept in their work on identity and agency that we believe is applicable to these young women. That concept is improvisation. Improvisations are "impromptu actions," "moments of resourcefulness," in the routines of every day when actors behave in ways that vary from normative societal expectations [11]. These improvisations offer opportunities for "heuristic developments," ways of fostering new or at least alternative social and material conditions for identity formation [11]. These girls and young women are not just products of or just respondents to their situations. Nor are they expressly taking a stance in direct opposition to their situations (at least not most of the time). Rather they are devising inventive and creative ways to participate. Their aim is not accommodation or liberation. They seek engagement.

These improvisations applied very directly when, as girls and young women, they found themselves dealing with (sometimes confronting) gendered roles and conventions. "I want and I can" encouraged resourcefulness and impromptu actions that in turn led to their engagement and participation regardless of roles and conventions. Holland et al. [11] refer to these as improvisations as a "significant means of renovation, which even the most powerful and

hegemonic regimes cannot preclude." They represent "creativity" and the possibilities for change [11].

Theme 2: As girls and young women, the participants engaged in a variety of extracurricular learning activities that were not confined or heavily weighted towards those associated with STEM. Indeed, in some cases, contrary to the current literature, the women participants were highly involved and excelled in liberal arts subjects and/or activities that would be traditionally regarded as "girly." Most important were the *experiences of agency*.

Idealized Case: Carson always enjoyed reading, writing and drawing. She was curious about things. She remembers being fascinated by space, following closely the experiments conducted on the space station and space probes exploring our solar system. However, she was just as interested in ancient Egypt and was hoping to someday learn Mandarin. She took pleasure in developing a deeper understanding. And, while she kept her options open about what she might pursue in her future, whatever Carson chose, she wanted to have an impact, to make a difference. She was attracted to results, tangible outcomes. Indeed, working, often quite hard, to realize results and/or outcomes was how she spent most of her time. She liked doing things, and she admired others who did things, especially those who realized results, outcomes. She respected expertise. Not in a way that was defensive (maybe just a little), Carson wanted to prove herself; mostly to herself. She also very much enjoyed (often a bit surprised) when she was recognized by others for her work and her accomplishments. Finally, she was reflective, not necessarily in a formal way, but still routinely reviewing what she was doing, why she was doing it and how she might get better.

Exemplary quotes from different participants supporting theme two.

"I did all sports and all that kind of stuff, and most of leadership was through that sports lens. And then in high school I picked up all the clubs, because for some reason my best friend and I thought the more bullet points on the resume would mean the better resume. I don't know why, but that's what we did. So each did like eight clubs, and between the two of us we covered every single club our small high school had, except for one; it was insane." [S1P1]

"I was involved in music and art heavily. My entire childhood. I took piano lessons, and opera lessons for ten years. I'm an opera singer. I was also in robotics, starting High School. Once I decided I wanted to be an engineer. I was like, "Oh, what do engineers do? Robotics!" So I figured I'd try it out and see how it goes. Um, I was still like doing opera and piano lessons and art after school during school I painted a mural in the library. I, I love doing all these things. And I don't think that they conflict with each other I think that they help, you know, the brain, learn. I'm sure there're studies on it, music and science and STEM." [S2P2]

"I did jump Rope Club in 8th grade, and then became a leader for that in high school. So, that was fun, like I learned like people management skills and communication skills, because I really wasn't good at communicating. And I know in engineering that sometimes there are people that are not particularly great at communicating and if you have an engineer who can communicate their ideas, and that's like valuable, so that was helpful. But I didn't really join any like technical clubs." [S3P2]

"I was a competitive Irish Sun dancer. I was like, Yeah, so my sister and I both did like little kid ballet for a while. My sister, and tap. And then my sister stuck with ballet, and I do not. .... I did Irish step and tap for probably all of middle school. And then by high school I had enough and focused on like; oh I like tennis. Yeah, that was when I switched ... I was on the tennis team for high school, and that was like my main athletic thing...." [S2P3]

"The only thing I was involved with was Key Club in high school, which is a community service club that a lot of universities will have. And through that I met a lot of friends.... And so that was the only thing I could really do as well. ..., as far as more engineering related organizations at my high school, either cost money that we couldn't afford, or it was limited." [S3P3]

Agency is variably defined and is ubiquitous across a very broad range of disciplines. We prefer to begin our attempt to understand the experience of these young women with an admittedly "bare bones definition," one offered by Laura Ahearn [12]: "Agency refers to the socioculturally mediated capacity to act." Contained within this definition are three important elements:1) a sociocultural context within which agency occurs; 2) various mediational means or instruments, materials, activities relevant within that context for realizing agency; and 3) an expression or a realization of participatory power, power at least potentially but not necessarily able to attain some effect.

Each of these women participated in a particular context, a community of actors: a sports team; a school club; a collective painting a mural, a dance troupe. They all understood themselves to be a participant along with others, to belong as a participating member within that community of participants. As a participant, each of these women employed some mediational means in order to participate: painting appliances and materials for the project team, musical instruments for the jazz band, a tennis racquet for the sports tennis team, their own bodies for the dance troupe. Their participation was always mediated through instruments, materials, activities meaningful within and peculiar to that context. Finally, through that participation they experienced power, or perhaps better said, empowerment. As athletes, they were able to take part. As artists, they were able to paint. As musicians, they were able to play. As dancers, they were able to dance. The experience of power or again empowerment was realized in their performance.

Theme 3: Not all of the women participants were in leadership roles, informal or formal, throughout their K-12 schooling. Nevertheless, what was common is that, through the academic and extracurricular engagements, they developed a confidence their abilities, a positive, assertive attitude, and a rejection of viewing failures as ultimate defining indicators of their abilities and potentials. Such represent *experiences of self-efficacy*.

Idealized Case: For Cody, school represented an opportunity to explore interests, to learn by doing new things. While she was a good student and took school seriously, Cody found school relatively easy. She was generally able in her math and science courses. What seemed most to capture her interest and demand more of her involvement were extra-curricular activities, e.g., clubs, competitions, sports. Her participation allowed her to explore, to better understand her interests and capabilities. Cody was rarely alone in these explorations. Each, as suggested

above, involved collaborating with others and developing relationships. It was through these collaborations and, as a result, those relationships that she gained confidence, developed greater sense of self-efficacy and belonging, especially in relation to her peers. Failure and success were generally shared. Leadership was also often shared. These extra-curricular activities seemed quite important for her positive identity formation. It was also important that Cody's participation in these extra-curricular activities was challenging and required a commitment. It was sometimes the case that the challenge and required commitment were actually more engaging than the activities themselves. Indeed, Cody understood that meeting the challenge or realizing tangible outcomes – win or lose – could be very positive for herself as well as for others. Those engagements that endured often became identity-defining.

Exemplar quotes from different participants supporting theme three.

"My junior year we got a new art teacher. So instead of like that quiet reserve, like only realism painting, stuck in the old dingy...school. .... And so, he put together like a mural team, and it is not a pretty mural. ... that was the first mural we ever did, and somehow, he's like, "You're gonna be in charge of this," he's like, "You've taken a painting for 3 semesters, you're the most senior member, you have to be in charge." I was like, "I'm, not qualified. This mural could be still ugly, you know. These kids get paid." You know. And that's how I got trust in my first like actual I would say project management role. .... But somehow me and a couple other members ended up coordinating this whole thing, and ... I was still Junior in High school...." [S1P1]

"In K-12 education, I was a part of CAP and, and JRTC. So, I was learning a lot about airplanes and ships. So, the mechanics of those. I was, of course, still into more of the engineering side. I, I, I liked to learn about how ships worked, and how planes fly. And I did many like signs, projects about them, and I, I ended up teaching a lot of people in the class that were taking it with me. It mainly had to do with physically building things that I was interested in. Those were the programs that I, that I went to." [S3P4]

"So, a project that I did before college. Online we have game jams, which is like make a video game within a week or in a day, and it's, it's, it's, it's a competitive thing where you can try to see like what bare bones thing can I do that can make something fun and original, and make it work. And well, like coding and getting something to work is like it has that amazing feeling, optimizing something, and actually making it usable for future uses is also like something that I enjoy doing. So, I used to do a lot of game jams back when I was in high school, and I, I guess it kind of set me on the course of being more, it kind of faced me with like the, the real-life way of how, how coding works. Because getting something done within a day or a week is a really hard task. So, learning to manage my time, and really set my mind on what I need to do, how to do it, what are the things that I need without looking at like the more obscure details, it, it really helped me see like the hard part about coding, and why people might not want to do it, and even then, I still wanted to do it. So, I guess it's kind of why I'm very into, I want to do coding, because I've been through the hard parts." [S3P5]

Self-efficacy is a key element of Social Cognitive Theory [13]. It "refers to beliefs in one's capabilities to organize and execute those courses of action required to produce given attainments" [14], or a "person's awareness of their ability to accomplish a goal" [15]. It is an affective state that serves as a powerful motivator. There are four kinds of experiences that can contribute positively to self-efficacy: mastery experiences, verbal or social persuasions, vicarious experiences, and psychological states. Self-efficacy has proven to be a powerful predictor of achievement in areas that range from the more general – learning, academic achievement, retention, mathematics – to the more specific – computing [15], engineering design [16], engineering modeling [17], and even tinkering [18] – just to name a few.

Each of these women exhibited self-efficacy. From their stories, examples of at least two of the kinds of experiences that engender self-efficacy are most prominent: mastery experiences and verbal or social persuasions. The first, encouraged by her teacher, took on a major project – "you're the most senior member, you have to be in charge" (confidence does not mean that one does not have doubts). The second because she wanted to "learn a lot about airplanes and ships," learned enough to demonstrate her mastery through teaching others. Finally, the third, having developed an understanding and appreciation of "the real-life way of how … coding works" and having mastered the "hard parts," she could imagine a future with her "optimizing something, actually making it useable," doing something that she enjoyed doing.

Critical engineering agency (CEA) is a very important concept when attempting to better understand women who are thriving in undergraduate engineering project teams [19-22]. It includes three constructs very much related to engineering identity formation: *interest*, *competence/performance*, and *recognition*. Interest is "students desire to participate" [21, 23]. Competence/performance involves "students' … ability to perform the practices of their discipline and understand the content of their discipline" [21]. And finally recognition is "students' perceptions of how others view them" [21]. We expect that CEA will prove most important when applied directly to the young women's experience of engineering project teams. There we are seeing abundant evidence of all three constructs and a robust development of something very much like CEA. However, we also claim that what we are discovering about early experiences of improvisation, agency and self-efficacy serve as fertile grounds for the later realization of CEA and engineering identity.

Conclusion

Returning to our original question: What can we learn from listening to women who are thriving in engineering project teams about their early experiences – STEM, engineering or otherwise? We learn that early experiences of improvisation or resourcefulness and creativity in relation to sociocultural norms enables doing what I want and I can. We learn that early experiences of agency or the capacity to act with power in a relevant context fosters future effectual actions in other contexts. We learn that early experiences of self-efficacy enable more and later experiences of self-efficacy and the all-important traits of confidence, resilience, persistence even more required in the masculinist culture of academic engineering. Finally, we learn that maybe it is more the qualities of the experience, less whether those experiences are directly related to STEM practices and activities or engineering specifically that empowers

women to thrive. This also may explain why the evidence for early STEM and engineering having much of an impact is limited, little detectable or at best not extensive. This is not to discourage girls from participating or having early STEM/engineering experiences, but we are arguing that such exposure may not be determinately necessary, and could have promoted (even when it is unintentionally) young girls to adopt a masculinized understanding of STEM/engineering, resulting in turn that understanding themselves as "outsiders." Research has found as early as 10 years of age, girls already begin to associate STEM/engineering with masculinity [7].

This work presents a step in a somewhat different direction than previous research with a common goal of increasing the number of women in engineering. We do not wish to discredit or devalue previous efforts, particularly through outreach programs geared at exciting the next generation of engineers. By telling the stories of women who are seemingly thriving in engineering, through our definition, we offer an alternative pathway to engineering programs. It seems that we do not need only to show why it is "fun to be an engineer" --girls and young women are certainly capable of discovering that on their own. Rather we should support them in these early experiences of improvising, agency, and self-efficacy because these experiences seem to contribute in important ways to engineering identity formation.

Acknowledgements

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