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Lived Experiences that Influence How Women Engineering Majors Describe Themselves as Creative

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Abstract

Engineering is a creative profession where diverse perspectives of both men and women are crucial to the field. The importance of better understanding the pipeline of female students into engineering, and the path to their success in the major is evident. In 2017, women comprised approximately 20% of engineering graduates, up from 18% in 1997, and 15% never entered the engineering workforce. In 2019, women comprised 48% of the workforce, 34% of the STEM workforce, and only 16% of practicing engineers, a 3% increase from 2009. In an effort to better understand these disparities, this mixed methods research investigated the creative self-efficacy (CSE) of women engineering majors and their beliefs about creativity in relation to lived experiences and explores the research question: In what ways do undergraduate women engineering students describe their creativity and how their lived experiences influenced their decision to major in engineering? The researchers investigated the lived experiences of women engineering students before they entered the engineering major in relation to the way they described themselves as creative. A survey of CSE and beliefs about creativity was administered to 121 undergraduate women engineering students who volunteered for this study. Interviews were conducted of 15 participants selected from survey results with different levels of CSE who met the researcher's criteria for success in the engineering major. The findings of this study lead to several conclusions: (1) students' descriptions of themselves as creative corresponded more with the arts than to innovation in engineering; (2) students who described themselves as less creative: (a) had a lower level of CSE; (b) had a greater exposure to engineering in high school through engineering-centered courses and clubs; (c) had a family member who worked in the profession; (d) described more negative classroom experiences at all educational levels that involved intimidation, isolation, and gender-bias.

Introduction

This study continues research conducted by Delahanty and Silverman (2021) of undergraduate women engineering majors, their level of creative self-efficacy (CSE), and lived experiences that lead them choose engineering as a major [1], [2]. The importance of creativity in engineering has been highlighted in the research and has been studied with respect to the success of women students in the engineering major and in industry [3], [4], [5], [6]. Women engineers offer diverse perspectives and innovative solutions, but comprise only 16% of the profession, a 3% increase from 2009, and only 20% of all engineering graduates, up from 18% in 1997 [7], [8], [9], [10]. In addition, 15% of women engineering graduates never enter the engineering workforce [5], [8]. The goal of this study was to determine how successful undergraduate women engineering majors with different levels of CSE, who identified with the engineering major, described themselves as creative in relation to the successes and challenges they faced in the pipeline into engineering [11].

Literature

This study builds upon existing literature that examined social and educational barriers that female students face in the pipeline to engineering and in the engineering major, creativity in the engineering profession and in education, and CSE in education. Details of the literature are presented in [1], [2]. Female students encounter numerous barriers in the pipeline to engineering. The obstacles are varied and include both educational and social factors. Social factors include negative perceptions of engineering as a profession for men, and gender bias both inside and outside of the classroom. Deficiencies in curriculum have been studied as major barriers, primarily within the traditional classroom that does not encourage a welcome atmosphere and that does not cultivate diversity, [4], [12], [13], [14]. Limitations include gender bias, lack of self-efficacy in math and spatial skills, a lack of adequate academic advising, a lack of awareness of engineering as a profession, and very few female mentors [5], [13], [15]. These factors have contributed to the lower numbers of female students choosing engineering, those completing the major, and to the small percentages women engineers in the profession [11], [14], [16], [17] [18]. Intrinsic and extrinsic motivation have been studied as factors related to the success of female students seeking engineering as a major [19], [20]. Identification, or a sense of belonging has been shown to be a factor related to success of female students in the engineering major [11].

Creativity in engineering has been studied as a factor in the choice of engineering as a major, in addition to the retention of women in the major and in the field [3], [4], [15], [21], [22]. Women are known to be major contributors to creativity and innovation in the engineering profession [3], [4], [23]. Creative self-efficacy (CSE) within engineering curriculum has been studied as a part of student success in engineering education, and with respect to the retention of women engineering students in the major [15], [24], [25]. Curricular and extra-curricular educational experiences that involve project based learning (PBL) and spatial reasoning are an integral part of engineering-centered curricula [26], [27], [20]. These experiences cultivate the creative aspect of the industry and have been shown to increase spatial abilities. They have been studied with respect to encouraging students to choose engineering as a major, and to their success in the major, particularly female students [5], [15], [15], [22], [27], [20]. The relationship between engineering programs that encourage an atmosphere that promotes creativity and the success of women engineering students in such programs is a significant need. Ultimately, this work supports the growing evidence that traditional engineering programs, as well as the K-12 pipeline into the engineering major, need significant restructuring to benefit all students, and to significantly increase participation of women in the engineering profession [4], [18].

Research Question

The following research question framed this study: In what ways do undergraduate women engineering students describe their creativity and how their lived experiences influenced their decision to major in engineering? This question was designed to better understand the lived experiences of undergraduate women engineering students in connection to how they described themselves as creative. It is our expectation that a better understanding of this relationship will lead to possible strategies for reform in the pipeline into engineering. It is expected that this reform will lead to an increase the number of pathways for female students into the engineering major, benefit all students, and contribute to increasing the numbers of women who choose engineering.

Methodology and Instrument

This study utilized a sequential explanatory mixed methods design [1]. The instrument used in this study was comprised of a CSE assessment, and a measurement of beliefs about creativity [1]. This survey was administered to undergraduate women engineering majors who volunteered for this study. Data from the quantitative and qualitative portions were analyzed separately, and the data was then synthesized to first to identify the interview participants, and then to help to answer the research question [1], [2]. The validated three question CSEI instrument was used to measure the CSE of the 121 survey respondents [1], [28], [29], [30]. An example question from the CSE instrument was, “I have a knack for solving problems creatively.” Answer choices to the three question CSEI, and the BACS, were in the form of a five-point Likert scale: “Strongly Disagree” to “Strongly Agree.” The score on the CSE instrument and demographic information were analyzed quantitatively by Delahanty and Silverman (2021) to help select the participants for the interviews [1], [2]. Qualitative analysis included first and second cycle coding to arrive at the themes and subthemes [31]. First cycle coding consisted of analysis of overlapping words, phrases, and patterns, that lead to emergent primary and secondary codes and themes. Second cycle coding analysis included a more in depth analysis of words, phrases, patterns, codes, and themes to consolidate and categorize results from the first cycle of coding. The two levels of qualitative analysis lead to the representative themes and subthemes that emerged from the interviews and that are discussed in the qualitative findings (See Table 2). Level of CSE was a distinguishing factor in both how participants described themselves as creative and in their lived experiences that influenced them to major in engineering.

Table 1. *Labels of Interview Participants for Discussion Distributed Based on CSE Level*

CSE Level	Number in Level (Total = 15)	Label for Discussion	CSE Level and Score from Survey (Range: 7-15)
Low (7-9)	n=5	L4	Low (7)
		L7	Low (8)
		L9	Low (9)
		L11	Low (7)
		L14	Low (8)
Medium (10-12)	n=6	M3	Medium (12)
		M5	Medium (12)
		M8	Medium (11)
		M10	Medium (12)
		M12	Medium (11)
		M15	Medium (12)
High (13-15)	n=4	H1	High (15)
		H2	High (14)
		H6	High (15)
		H13	High (13)

Population

Survey respondents included undergraduate women engineering majors who were contacted from two participating institutions, and a professional engineering organization for women (recruitment venue that included members from colleges and universities within Philadelphia and the surrounding region). All of the survey respondents reported in the demographic portion of the survey that they were between 18 and 24 years of age. Survey respondents who expressed an interest for an interview in the demographic portion of the survey, and who had a GPA of 2.5 or above, and successful completion of calculus II, were invited to participate in a semi-structured interview. The researchers' criteria for an interview indicated a level of success in the major, identification with the major, and the potential for completion of the major [1], [11]. In addition, participants were chosen based on CSE scores that were in the low, medium, and high CSE range to add additional depth to the analysis, and for comparison purposes. Table 1 shows the *Label for Discussion* of the 15 participants for from the qualitative findings that are representative of the CSE levels from the survey (L: Low (n=5), M: Medium (n=6), H: High (n=4)), where the levels are evenly distributed. The number following the level that indicates the order in which they were interviewed [1].

Findings and Discussion

Table 2 (adapted from Table 8, p.12 in [1]) provides a summary of the three major themes and related sub-themes that emerged from the qualitative data analysis that helped to answer the research question. The three major themes that emerged from the qualitative analysis were: (1) Pathways into Engineering, (2) Breaking Barriers to Engineering as a Major, and (3) Success as an Engineering Student, which included how participants described themselves as creative. Levels of CSE were significant in how the participants described themselves as creative and in their lived experiences that influenced them to choose engineering as a major. How these students described engineering as creative also connected to how they described themselves as creative.

How the undergraduate women engineering majors described themselves as creative. Participants with all levels of CSE described themselves as creative, first as either talented or not talented in the arts. As a secondary description, some then discussed their creativity as "ideas" or "innovation." Seventy three percent (73%, N=11) of the 15 participants indicated that they were either artistic or not artistic, and referenced artistic talent in how they perceived themselves as creative. Eighty percent (80%, n=4) of participants with the lowest levels of CSE described themselves as not creative and reported that they lacked talent in the arts. Forty percent (40%, n=2) described it in terms of innovation, and none of these participants expressed that they had talent in the arts.

Participants reflected on the interview question, "Describe how you view yourself as a creative person." Eighty percent (80% , N=12) of all participants reflected on artistic talent as a primary measure of creativity, and 73% (N=11) referenced innovation. A notable difference of students with the lowest levels of CSE was that only 40% (n=2) of these students mentioned innovation, in contrast to 83% (n=5) and 100% (n=4) of participants with medium and high CSE respectively. Participants with higher CSE highlighted their talent and enjoyment of the arts before reflecting on themselves as innovative. H1 indicated that, “I did a lot with like music and performing arts. I like that aspect of creativity, more like an artistic way. But I'm a big problem solver and I always like to find a different way to solve things” (H1). M12 was another participant who connected her creativity to artistic talent, “I like to think I'm a very creative person. I've, I've always been artistic my whole life…” (M12). When asked about engineering as creative, M12 referenced engineering as creative in the answer to that question, but “not in the artistic sense” (M12). She discussed the creative thinking needed within “developing solutions.” L4 continued to refer to herself as not creative as part of a discussion on engineering as creative, but reflected on how her involvement in engineering was something that increased her level of creative thinking, “It makes you think in a very different way. I wouldn't say because I don't believe that I'm a very creative person. I always struggled in other subjects, especially anything to do with art or any of that. But engineering has made me think more creatively and more. And I'd say more innovative and thinking differently, which should be described as creative but is often misused. I guess” (L4).

Table 2. *Summary of Interview Responses from the Three Themes Related to this Research Question, and Related Subthemes (adapted from [1], Table 8,p. 12)*

Themes and Subthemes Derived from Qualitative Analysis of the Interviews	Participant CSE Levels*			Totals* (N=15)
	Low (n=5)	Medium (n=6)	High (n=4)	
Theme 1: Pathways into Engineering				
Exposed to project based learning	100% (n=5)	100% (n=6)	100% (n=4)	100% (N=15)
Took elective engineering-centered courses	100% (n=5)	50% (n=3)	50% (n=2)	67% (N=10)
Extra-curricular high school STEM activities	60% (n=3)	17% (n=1)	25% (n=1)	33% (N=5)
Other activities that encouraged engineering	80% (n=4)	67% (n=4)	50% (n=2)	67% (N=10)
Discussed mentors and role models	100% (n=5)	100% (n=6)	100% (n=4)	100% (N=15)
Family member who worked in engineering	80% (n=4)	50% (n=3)	25% (n=1)	53% (N=8)
Theme 2: Breaking Barriers Engineering as a Major				
Discussed breaking barriers	80% (n=4)	50% (n=3)	75% (n=3)	67% (N=10)
Traditional K-12 classroom	80% (n=4)	50% (n=3)	50% (n=2)	60% (N=9)
Negative perceptions of engineering	80% (n=4)	83% (n=5)	75% (n=3)	80% (N=12)
Theme 3: Success as an Engineering Student				
Described own creativity within “artistic” talent	80% (n=4)	83% (n=5)	75% (n=3)	80% (N=12)
Described own creativity as ideas or innovation	40% (n=2)	83% (n=5)	100% (n=4)	73% (N=11)
Detailed an artistic talent within creativity	0% (n=0)	83% (n=5)	100% (n=4)	60% (N=9)
Able to describe engineering as creative	100% (n=5)	67% (n=4)	100% (n=4)	87% (N=13)

***n** refers to low, medium, and high CSE levels, and **N** refers to entire sample of interview participants

Participants with both medium and high levels of CSE referred to themselves as innovative after they highlighted themselves as artistic. A notable distinction between participants with low CSE and participants with medium and high CSE was how they described themselves as creative. Most of the participants with low CSE described themselves as not artistic, and although some referenced an art in a discussion of their activities, none of them highlighted a talent in the arts. L7 connected her lack of creativity to her dislike of the arts, “I would not think of myself as that creative, which I guess is not very good in this field. I guess I don't really do like that much artsy stuff….” (L7). Another participant with low CSE, L11, expressed her belief about creativity as being connected to art, “I think a lot of creativity in general is kind of associated with art. So as like I've always been a math and academic person, so I've never really viewed myself as creative” (L11).

Two themes of the three major themes emerged from questions that focused on K-12 experiences in the pipeline into engineering that influenced participants to choose engineering as a major: (1) Pathways into Engineering, and (2) Breaking Barriers to Engineering as a Major. The first theme related to lived experiences that emerged was “Pathways into Engineering.” All (100%, N=15) participants recounted having successes in traditional science and math courses prerequisite to the engineering major. Sixty seven percent (67%, N=10) of participants took engineering-centered elective courses in high school such as engineering design or coding courses. A notable difference between CSE levels was that all participants with the lowest levels of CSE (100% or n=5) took these engineering centered courses in high school, and 60% (n=3) of these same participants described extra-curricular STEM based teams or clubs in high school, whereas 17% (n=1) with a medium level of CSE, and 25% (n=1) with the highest levels. L4 reflected on the value of two pre-engineering courses involving computer aided design (CAD), and discussed the positive influence they had, “if I didn't have that experience of those just two, like intro courses, I would not have been confident enough to go into engineering.” Another participant with the lowest levels of CSE, L7, recalled, “Like my junior year, I joined my high school's robotics team and I think that very much like shaped me being more like me wanting to be an engineer.”

All participants (100%, N=15) discussed mentors and role models who played a major role in influencing them to choose engineering by supporting them, raising awareness of engineering as a career option, and instilling confidence in them through their interactions. Mentors included teachers, coaches, and parents. M10 reflected on support from her father, “He [dad] was always really encouraging… So that was like part of the reason why I wanted to choose to do engineering.” H13 recounted the support from her mother who was an engineer.” My mom, who is an engineer herself, was always just excited about getting me involved and like seeing her daughters sort of like pursue those, like, interests.” There were 53%, (N=8) of all participants who had a family member who worked in engineering or a closely related field. Eighty percent (80%, n=4) of participants with the lowest levels of CSE reported that they had a family member in the field, in contrast to 50% (n=3) with medium CSE, and 25% (n=1) with the highest levels of CSE. This was a notable difference among those participants with low CSE. Some participants with low CSE reflected on their parent’s skepticism with respect to their choice of engineering as a major, “I think they're just like very worried about me just because that's unconventional….’I don't know if that's for you,’ but he [dad] wasn't like against it or anything” (L7). Instead of referencing parents, participants with low CSE highlighted encouragement from their teachers and coaches, L7 recalled, “I think my computer science teacher was really, really influential with it. He really pushed engineering, especially for girls, because like, that's not something that girls are a big part of” (L7). Another participant with the lowest levels of CSE, L4, recounted how her male robotics coach, who was also her precalculus teacher, pushed her to achieve, and encouraged her to try engineering, “He pushed me more than anyone to do engineering…” (L4).

The second theme related to lived experiences that emerged was “Breaking Barriers to Engineering.” Major factors in helping participants break barriers to engineering were overcoming intimidation, lack of confidence, and a variety of academic struggles, and persevering in the traditional classroom. Eighty percent (80%, n=4) of participants with the lowest levels of CSE referenced the traditional K-12 classroom as being a barrier, in contrast to participants with both medium (50%, n=3) and high (50%, n=2) levels of CSE. Another barrier to engineering was that participants with all levels of CSE did not know what engineering was until they were enlightened to it. Both intrinsic (perseverance and self-awareness) and extrinsic factors (support from mentors and role models) played an important role in the success of these female students [20], [19] . One participant with a low level of CSE, L4, reflected on how difficult concepts in school didn’t come easy to her and the work she had to put into her studies, “I just tend to work harder, but I had to work harder because it didn't come this natural to me as it would come to them” (L4). Another participant, M5, who also struggled in her AP calculus course, overcame that as a barrier, “I started working really hard… I liked putting in hard work and seeing that I can, I can get smarter, and I can learn things if I put my mind to it” (M5). Although a calculus class caused M8 to question choosing engineering as a major, she reflected on her increased self-awareness, and confidence she gained in her high school engineering courses, “But I continued to take the engineering classes on the side, and I was pretty good at those. So, I think I kind of convinced myself that, yeah, I could do engineering…” Reputation helped to motivate one participant, M15, who was known to have an aptitude for math, “But I think that definitely like being known as someone who is good at those sort of things kind of pushed me into doing engineering.”

Barriers that were discussed also included the traditional classroom that involved struggles with a male students and with intimidating teachers. One participant M5 reflected on the male dominated STEM classroom, “I'm kind of left on my own. I don't really get a partner. So, yeah, I would say that's my biggest barrier” (M5). L9 also expressed her feeling of isolation as one of only a few female students in her traditional high school courses that prepared students for engineering, and L4 questioned how she would fit in with male students in the engineering major, based on her negative experiences with them in the K-12 classroom, “And so, I was a lot of I was just scared because a lot of guys intimidated me and liked to show off and try to prove to you that they are better than you and they were smarter than you. And I'm a very let's work together type of person vs. I can do this better than you.” Breaking barriers by overcoming intimidation as a member of engineering centered clubs was a topic that was also highlighted. One participant, L4, who had a low level of CSE reflected on how she joined the management side of the robotics team because she was intimidated by the engineering side, “I wanted to be like doing things with my hands and stuff, but I was always just too intimidated to do that.”

Negative experiences with teachers caused some of the participants to lose confidence in their abilities to choose engineering as a major. Participants with higher levels of CSE reflected on “fighting back,” determination, and increased self-awareness of their abilities. M10 recounted how a negative teacher actually helped to influence her to choose engineering as a major, “I remember my Algebra 2 teacher told me explicitly that she didn't think I would be able to handle taking pre-calculus and she didn't think I'd be able to handle engineering as she expressly told me that I shouldn't do it… I think, like my personality was kind of like, I'll show you.” H13 also described experiences with some teachers that made her question her abilities, “I think times when I had a younger, less encouraging teachers or teachers that made me feel confused. That was a little bit discouraging because it made me a little bit worried about my abilities to sort of like continue those subjects at a high level." H13 described how she overcame this barrier to engineering as a major through developing her skills in math and gaining more confidence in her abilities, "But as I sort of gained the skill base, I would develop in my ability and be more confident."

In the pipeline into the engineering major, not knowing what engineering is was a major barrier for most of the participants. Eighty percent (80%, N=12) of all participants interviewed indicated that in their K-12 experience, they did not know what engineering was until someone enlightened them to engineering as a career choice, and 80% (N=12) described negative perceptions of engineering before they entered the major, regardless of whether they had a family member working in the profession. "I just thought of it as more just math, science, kind of very nerdy and logical" (M3). "I really didn't know much about it or what it entailed. It sounded kind of dorky to me… I pictured engineers as guys and like hardhats and construction vests… I didn't really see myself doing that" (H1). "It's really intimidating to me, this word engineering. It is only the really intelligent people doing it, right? A lot of math" (H2). L9 discussed gender in her initial view of the engineer, and expressed her fear of being in a room "filled with a bunch of guys who wouldn't talk to me"… "the big nerds, you know, like the geeky guys who don't know how to talk to people and aren't creative" (L9). M8 reflected on her limited view of engineering, "I think my understanding of what engineering was, was kind of like, oh, construction worker, like the person that designs things…." (M8). M5, a mechanical engineering major, reported how she perceived engineering, "I think nobody really knows what engineering is. I think they think we just make bridges and buildings….Nobody really knew. I especially didn't know what engineering was. I thought it was just the hardest possible subject that, and, you know, doctor programs and med school and things like that."

The way the undergraduate women engineering majors who demonstrated a level of success and identification in the major described themselves as creative or not creative was a major factor that distinguished them in connection to lived experiences that influenced them to major in engineering. Most of the participants described themselves as creative or not within the arts and less as innovative in engineering. Participants with the lowest levels of CSE distinguished themselves from the other participants, where most described themselves as not creative, and none of them highlighted a talent within the arts. There were several K-12 lived experiences that distinguished participants with lower CSE levels: (1) most had a greater exposure to engineering through (a) pre-engineering or coding courses in high school, and STEM based clubs, and (b) a family member who worked in the field or a closely related field, and (2) most expressed negative experiences within the traditional K-12 classroom that included intimidation, gender bias, a feeling of being alone, and a lack of creativity in the pre-high school classroom, and they did not discuss strategies like "fighting back." In addition, the one participant in the medium group who described herself as not creative also discussed negative classroom experiences and participation in engineering centered experiences in high school, such as courses, and robotics club. This was an interesting connection between a participant with a medium level of CSE, and those with a low level of CSE. She, however, reflected on a high level of support from her parents, and did not indicate that she had a family member who worked in the profession.

All of the participants with a high level of CSE and most with medium CSE described an artistic talent that related to how they described themselves as creative, and highlighted a lived experience they excelled in within the arts before they entered the engineering major. Most did not initially connect how they described themselves as creative directly to engineering, but they were also able to describe themselves as creative within innovation. Like participants with medium and high CSE, participants with the lowest levels of CSE broke barriers to engineering through intrinsic factors such as self-awareness and personal growth, and extrinsic factors such as positive personal influences and exposure to engineering centered experiences. Participants with all levels of CSE had negative perceptions of engineering before entering the major, even those who were exposed to more engineering-centered experiences in high school, and who had a family member who worked in the field. And these two lived experiences distinguished participants with the lowest levels of CSE from the other participants. How engineering related experiences in high school, and having a family member in the engineering profession affects undergraduate women engineering majors needs further investigation to determine if these two factors contribute to both CSE and how these students describe themselves as creative.

Conclusions and Future Research

The findings of this study lead to several conclusions: (1) most of the participants (a) had negative perceptions of engineering before entering the major, (b) described themselves as creative more within the arts and less as innovative in engineering; (2) students who described themselves as less creative: (a) had a lower level of CSE; (b) had a greater exposure to engineering in high school through engineering-centered courses and clubs; (c) had a family member who worked in the profession; (d) described more negative classroom experiences at all educational levels that involved intimidation, isolation, and gender-bias. The findings and conclusions indicate that future research is needed to address educational reform at all educational levels involving, (1) how engineering and creativity and their connection are defined and described, and (2) how the creative aspect of engineering within PBL, that helps to increase spatial abilities and cultivates innovation, is beneficial to all students, particularly female students. Future research includes extending this study to a wider audience of undergraduate women engineering majors to further investigate lived experiences of these students and their level of CSE in relation to how they describe themselves as creative. It is expected that this future research will increase awareness of the educational reform needed in engineering education, that will help to prepare a more capable, diverse, engineering workforce.

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