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Fostering Female Belongingness in Engineering through the Lens of Critical Engineering Agency*

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The need to increase the number of underrepresented groups in engineering is a moral as well as socioeconomic imperative. Women have been traditionally underrepresented in engineering in the U.S.; understanding how women identify with engineering and see a career in engineering as a means to positively impact the world may begin to address this persistent gap. This work reports on a qualitative study which gathered open-ended survey responses from 46 women enrolled in college engineering. Using the previously-developed Critical Engineering Agency (CEA) framework to understand how women identify with physics, math, and engineering, we provide insight into the ways in which women can feel they belong in engineering. Fostering this belongingness may begin to create lasting ties between women and their engineering majors and may help to retain more women in the first few years of college, when they are more prone to leave.

Keywords: Critical Engineering Agency; identity; women in engineering

1. Introduction

The underrepresentation of women in engineering is a persistent issue despite significant effort and research focused on the topic. The groundbreaking work of Seymour and Hewitt cited several reasons why talented women leave engineering including feeling a lack of belonging within engineering as opposed to any lack of talent [1]; a finding still supported by more current research [2]. Other research has found that the experiences of female undergraduates in engineering are different than those of men [3–5]. While women persist overall at the same rate as men, they tend to leave engineering earlier than males, usually during their freshman year [6]. Despite the fact that female participation in many STEM disciplines has increased dramatically over the last thirty years [7], the field of engineering still awards on average only 27.2 percent of bachelor's degrees in engineering, manufacturing, and construction to women internationally. Several developed countries award fewer bachelor's degrees to women than the global average: United States—21.7%, United Kingdom—22.6%, Australia—24.3%, Canada—23.5%, and Japan—11.1% [8]. Recent calls from the President of the United States have been made for *one million* new STEM graduates in the next ten years [9]. In order to meet this demand, a new and diverse engineering workforce needs to be identified, prepared, and retained in engineering. Increasing the number of women who pursue careers in engineering can begin to address some of these needs.

Additionally, the attrition rate for engineering majors, 48% among bachelor's degree candidates, results in a significant loss of talented and potentially successful individuals [10]. In order to meet the goal of more engineering graduates, more students need to not only be recruited into engineering but retained for the entirety of their undergraduate careers. Increasing the number of students graduating in engineering by 10% can make a significant dent in the national deficiency [9]. Understanding how women identify with engineering and develop an engineering identity can illuminate ways in which women can feel belongingness within an engineering Community of Practice [11]. Creating an atmosphere which is conducive to women's feelings of belongingness may increase educators' abilities to not only recruit but also retain a broader diversity of students.

1.1 Theoretical framework

Critical Engineering Agency (CEA) is used to understand how women match their identities and beliefs about what they can do with engineering, agency beliefs, with their experiences in engineering. This framework was built from Critical Science Agency developed by Basu and Calabrese Barton [12–14] which highlights three core principles of how students become empowered within a particular field. Students must: "gain deep understandings

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of [the subject] and the processes, skills and modes of inquiry associated with this content, identify themselves as experts in one or more realms associated with [the subject], and use [the subject] as a foundation for change, such that their identity develops, their position in the world advances, and/or they alter the world towards what they envision as more just'' [15, p.374]. Previous work adapted and validated this framework for engineering from its original roots in a physics context [16-18]. This work presents the first application of CEA in explaining women's experiences in STEM fields in college.

In the emergent framework of CEA, identity is defined as the authoring of one's self within a particular context and is a continually evolving, self-reflexive process in many senses [19]. Domain-specific identities, mathematics and physics, are comprised of three dimensions of student self-beliefs: their performance/competence, recognition, and interests/beliefs [20]. These constructs have been validated using large-scale national data [16]. Additionally, this work situates CEA within the engineering experiences of women in college. Students' performance/competence beliefs represents their beliefs about their ability to perform effectively (e.g. on an exam in a subject) and be competent in a particular domain. The recognition component of identity consists of a student's beliefs that they receive external recognition from parents, peers, teachers, etc. as a good student (or ''kind of person'') in a domain/subject (e.g. ''mathematics person'' or ''physics person''). Interest in a particular domain also plays a key role in students' identity and their career choices. Previous studies have shown that students who are interested in engineering show particular interest and skill in math and science [21], and that these identity constructs are predictive of students' choice of engineering as a major in college.

A deepening understanding of these domains along with identification as the type of person that does math or physics is one component of CEA. The other part involves students seeing engineering as a foundation for change not only for their own selves, but to make positive changes in the world around them. This facet of the framework involves students' agency beliefs. These beliefs refer to students' perceptions of their ability to change their world through everyday actions and their broader goals. Students' agency beliefs involve how students see and think about STEM as a way to better themselves and the world along with being a critic of themselves and science in general [18]. The ''critical'' aspect of CEA is not simply making negative judgments, but involves the ways in which students become evaluators of STEM (in the sense of being critical thinkers) as well as become critics of themselves and the world through self-reflection. Being a critic, in this latter sense, is defined as evaluating, judging, and analyzing. The development of CEA can subsequently lend to students' professional identity development, advance their position or status in their community, society or the world, and/or alter their world in ways they envision through science and engineering.

This framework has been used to understand students' engineering choices as the transition from high school to college and compare differences in domain-specific identities and agency beliefs for men and women [18]. Women have statistically weaker associations between their physics and math identities and choosing engineering, but significantly stronger links to their agency beliefs than men. Additionally, out of the three sub-constructs of identity, students' beliefs of recognition by family, teachers, and peers were more important for predicting domain-specific identity than interest or performance/competence. The current work builds upon these previous findings by understanding how engineering women in their college career navigate the alignment of these prior beliefs and identities with their experiences in their first few years in engineering studies. If women enter engineering with specific agency beliefs and do not feel that their engineering experiences align with their expectations, they may be more likely to leave. Additionally, women enter engineering, on average, with lower physics and math identities than their male counterparts. This work investigates how these mathematics and physics identities adapt within an engineering context as well as how engineering identities from for female students in engineering.

1.2 Research questions

This study addresses the following research questions to understand how female students' discuss their self-beliefs, how these self-beliefs are formed, and what practical implications these findings have for engineering educators:

1. How do women identify with physics and math in college?
2. What do women believe they can do with an engineering/science career?
3. What factors influence women's identities and agency beliefs?
4. What experiences foster an engineering identity in college?

2. Methods

We used qualitative methods in this study because this approach allows the researcher to capture the individual's point of view. Qualitative research can study the individual's perspective and beliefs through detailed interviewing and observation. Additionally, this approach allows the researcher to incorporate a broad range of contexts and the effects of the social world writ large on the data and associated interpretations. Finally, this approach facilitates the collection of rich, descriptive data, which can explicate theory or develop understanding of how and why the trends seen in quantitative data occur.

2.1 Participants

Women who participated previously in the Sustainability and Gender in Engineering (SaGE) survey (https://engineering.purdue.edu/ENE/Research/SaGE_survey_Godwin_2014) [22] and who had engineering career interests (e.g. those indicating either a "3" or "4" on an anchored scale from "0—not at all likely" to "4—extremely likely" for the likelihood of choosing a career in engineering) were identified as potential participants for this study.

The SaGE survey was a large-scale study of students in introductory English courses enrolled in colleges across the U.S. (NSF GSE 1036617). The survey was administered in required introductory English courses to capture a sample representative of both STEM and non- STEM majors. Samples were taken from 61 institutions at two time points—Fall 2011 (6,772 respondents) and Fall 2012 (937 respondents). The survey instrument focused on student backgrounds, pedagogical factors in physical science classrooms, classroom achievement, and student attitudes toward STEM and sustainability. The intent of the study was to focus on factors that increased enrollment and retention in engineering majors and to explore the connections between engineering and sustainability-related topics in students' experiences.

Both students from the initial SaGE survey deployment in Fall 2011 and the targeted oversample from eleven 4-year engineering schools conducted in Fall 2012 were used in order to have the largest pool of potential participants. These students were recruited via email and offered a small incentive to participate in this study. Only female students who indicated interest in engineering on the SaGE survey were sampled, and the framework of CEA was used to examine differences in students with the "same" engineering career goal. These students were asked a variety of questions about their math and physics identities, agency beliefs, perceptions of engineering, and career expectations and influences (See Appendix B for the complete list of questions). The total number of female engineers who had previously provided contact information in their initial participation in the SaGE survey was 302. A total of 46 women responded to the open-ended survey (representing a 15% response rate) and this group provided an adequate number of student responses to begin to establish explanatory links between identity, agency, and the empowerment felt by these women who were interested in engineering.

2.2 Directed qualitative content analysis

For this qualitative study, directed qualitative content analysis was used to understand the underlying themes and ways that female students develop CEA. Qualitative content analysis consists of a family of techniques for systematic text analysis developed by Mayring and colleagues 35 years ago in a longitudinal study about psycho-social consequences of unemployment [23]. This technique traditionally analyzed large amounts of text into a number of categories that represent meaning [24]. Qualitative content analysis has moved past its more quantitative origins to the interpretation of content through a systematic process of coding and meaning-making.

Directed content analysis works with previously formulated, theoretically derived aspects of analysis by connecting them with the textual data. The goal of a directed approach to content analysis is to validate or conceptually extend a theoretical framework or theory. Thus, this approach is particularly apropos for understanding CEA in context. Existing theories or research can help focus the research questions addressed in qualitative research. Such a directed approach can provide predictions about the variables of interest or about the relationships among variables, thus helping to determine the overarching themes or relationships between codes [23]. Fig. 1 illustrates the overarching process of directed qualitative content analysis as described by Mayring [23]. The only part of Fig. 1 that has changed dramatically over the last 14 years is the type of evidence accepted for qualitative content analysis. Instead of the "quantitative steps of analysis" typically used in traditional qualitative content analysis, excerpts of discourse [25] and conceptual networks can be used [26]. Taking a direct approach means that researchers begin by identifying key concepts or variables as coding categories. Next, operational definitions are determined using theory [24].

The general steps for qualitative content analysis are included here [27]:

1. Prepare the data – The choice of the content must be justified by the research questions [28].
2. Defining the unit of analysis—The unit of analysis refers to the basic unit of text to be classified during content analysis. For this study, each open-ended survey was one unit.

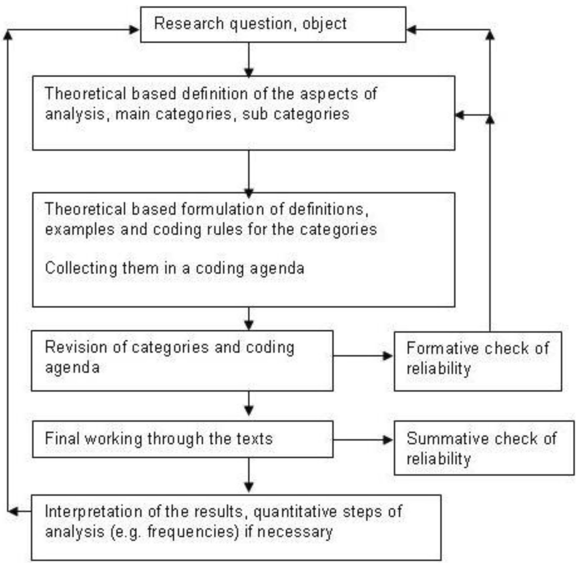

Fig. 1. Step model of directed qualitative content analysis [23].

3. Develop categories and a coding scheme—This analysis is directed. In this approach, researchers use existing theory or prior research to develop the initial coding scheme prior to beginning to analyze the data. As analysis proceeds, additional codes are developed, and the initial coding scheme is revised and refined. Researchers employing a directed approach can efficiently extend or refine existing theory [24].
4. Test coding scheme on a sample of text—This step involves validating the coding scheme through a detailed code book and conducting inter-rater reliability testing to ensure codes are consistent and reproducible.
5. Code text—The actual coding process uses a constant comparative method (described below). This method is used to prevent "drifting into an idiosyncratic sense of what the codes mean" [25, p.33].
6. Assess coding consistency—This step ensures reliability that the entire unit of analysis was coded consistently. Additionally, code meanings may have changed subtly over time and this step works to ameliorate inconsistent coding [26].
7. Draw conclusions from the data—This is the point at which the researcher makes sense of the themes or categories identified, and their properties. Researchers make inferences and present their reconstructions of meanings derived from the data.
8. Report methods and findings—For the study to be replicable, it is necessary to monitor and report the analytical procedures and processes as completely and truthfully as possible [28].

The qualitative analysis of Step 5 consists of a methodologically controlled assignment of a code to a passage of text. The main idea of defining specific steps in this qualitative analysis is to give explicit definitions, examples and coding rules for each deductive category, determining exactly which circumstances under which a passage can be coded [23]. Those category definitions are put together within an *a priori* (see Appendix A). In addition to coding deductively, emergent ideas and connections related to the theory of CEA are developed and understood inductively.

Data collected in directed qualitative interviews are often comprised of open-ended questions followed by targeted questions about the predetermined codes. To analyze the data, two steps are taken using a constant-comparative method. First, the data are coded with the *a priori* codes. Any other text that was not categorized with the initial coding scheme is examined to see if it is a subcategory of an existing code or it is given a new, emergent code [24]. These findings can offer supportive and non-supportive evidence and connections for CEA. Evidence is usually presented by showing codes with exemplars and by offering descriptive evidence [27]. Newly defined codes can offer a contradictory view of the theory or more fully articulate and extend CEA. The software used for this coding process is RQDA, an open source qualitative analysis tool [29].

2.3 Reliability and validity

Because this approach analyzes the data with *a priori* codes, a risk is that a significant, interpretive researcher bias could be introduced during analysis. To neutralize the potential for finding only supporting evidence for CEA and/or excluding contextual aspects, an audit trail can be used [24]. By working with other researchers to define the *a priori* codes, establish inter-coder reliability, and come to a consensus on the application and meanings of these codes to the data in context, the accuracy and veracity of the findings can be established and triangulation with other studies can be conducted. Formative assessment of reliability was conducted using the authors' entire research group to vet *a priori* codes. This process is conducted to ensure that while coding, the codes developed from theory are manifested and defined in an inclusive way. Summative assessment of reliability occurs after coding, this process included inter-coder reliability assessment for dependability with a resulting Cohen's κ of 0.954 (standard error 0.045). Additionally, the percent agreement between the coders was 96%. These values indicate "very good" reliability of the *a priori* codes and ensure summative reliability [29]. The area in which the coders did not agree was the interpretation of the significance of others asking students for help in a subject. While this code may seem like a recognition experience, it loads onto the performance/competence factor in an exploratory factor analysis [16]. A note was added to the *a priori* code book to clarify this issue for future coding.

Trustworthiness in qualitative research can be established through four criteria: credibility, transferability, dependability, and confirmability [31]. Credibility refers to the "adequate representation of the constructions of the social world under study" [31, p. 436] and can be assessed both in terms of the process used in eliciting those representations and in terms of the credibility of those representations for the community under study. Activities that work toward credibility include a prolonged stay in the field, persistent observation, triangulation, the search for negative cases (comparators), the establishment of referential adequacy by setting aside some portion of the data for testing of conclusions, discussions or debriefing with peers, and checks of results with members of the community under study. In this work, the triangulation of quantitative and qualitative data as well as several sources of data used in other analyses; regular discussions within the research team; and checks of the results with the literature and data set were used to establish credibility of the data.

Transferability refers to "the extent that the researcher's working hypotheses about one context apply to another" [31, p. 436]. The researcher's responsibility is to provide enough data, through rich, ample description, to allow these judgments to be made. In this qualitative work, transferability was addressed by understanding the broad context of CEA constructs in open-ended surveys. These responses give a breadth of answers that may transfer to other cases.

Dependability refers both to "the coherence of the internal process, addressed primarily through the concept of an internal audit, and to the way the researcher accounts for changing conditions in the phenomena" [31, p. 437]. Dependability was established by establishing a clear process by which the data were analyzed. Each step of the directed qualitative content analysis was documented.

Confirmability refers to the extent to which "the characteristics of the data, as posited by the researcher, can be confirmed by others who read or review the research results" [31, p. 437]. This process has been described as needed explicitness of data collection methods; analytic constructs documented by data; negative instances displayed and accounted for; personal, professional, and theoretical biases discussed; analysis strategies articulated; and documentation of the field decisions that altered research strategies [32, p. 148]. These two factors were established by creating a clear sense of how the data were analyzed and the specific codes used (Appendix A). The data collection protocol is included in Appendix B. Throughout the process of understanding CEA and analyzing the qualitative data included in this dissertation, the concept of trustworthiness was embedded.

3. Results

3.1 Agency beliefs

Students described their agency beliefs with varying degrees of depth and personal affiliation. While almost all students described engineering as a way to benefit the world with specific examples when prompted, some women exhibited stronger agency beliefs even when unprompted. When asked what some of the most important influences on choosing engineering, some women described their desire to pursue an engineering career specifically to make an impact in the world:

> Student 12: *I've also been surrounded by a lot of illness in my family and it has inspired me to devote myself to a career that helps people get over their illnesses (in this case, through developing medical devices).*
>
> Student 12: *[Engineering will] give me the tools and resources I need to make an impact. . .*
>
> Student 14: *I'm assuming some science goes into surgery, so when I had my knee surgery a few years back that mattered. I've taken a number of science/math/computer design courses, so on my way to becoming an engineer [sic] has impacted me. And if I ever develop a mortal sickness then hopefully the field of medicine will have advanced far enough that it isn't so deadly.*
>
> Student 18: *I hope to improve the quality of life within the world.*

These unsolicited agency-related responses show students with stronger agency beliefs that directly cite wanting to make a positive change in the world as the reason for choosing engineering. Agency beliefs are not a binary outcome, but are part of a spectrum for how individuals view engineering as a way to change the world. Our earlier work showed that agency beliefs are more important for women in choosing engineering than for men [18]. Even when asked what engineering can do for the world and for their lives personally, many women responded with answers beyond the identification of new technologies (e.g. cell phones and computers). These responses illustrate the depth to which these students believe their chosen careers can have positive social outcomes:

> Student 23: *Science and engineering keep society moving forward, improve quality of life, and can give hope and purpose to a person that uses the science to do work.*
>
> Student 10: *Technology and innovation are the only ways to achieve any progress as a society. Science and*

engineering can help create vaccines and medicines to *cure cancer and other deadly diseases. Science and engineering can discover ways to prevent the negative effects of global warming or find a place where humanity can live if we kill this earth.*

Student 27: *Science and engineering impact my life in so many ways including the buildings that I sleep and study in, and the medicine I take to stay healthy.*

These students spoke about science, engineering, and technology as the way to make life better for people and for themselves. When asked about what science/engineering could do, students spoke about the impact on their career in a variety of ways from social impacts to personal experiences to globally relevant issues. These students showed a breadth of understanding of the possible impacts of engineering. Some of this insight may be due to being involved in an engineering major for some period of time, and it may also indicate a better understanding of what engineers can do.

In previous studies, the measurement items for agency beliefs included "science has taught me to take care of my health," which seemed somewhat different from the rest of the items that loaded onto agency beliefs [16]. From the current data, connecting engineering and science with medical improvements and personal health is a natural extension of the positive impacts of engineering for students. Women describe engineering in this way and have a statistically larger path coefficient between agency beliefs and the choice of engineering in college. These responses that tie engineering to socially impactful, health-related, and environmental outcomes may explain why women are represented in higher proportions in engineering disciplines that directly address helping people and the environment including biomedical (39% women), chemical (33% women), environmental (46% women), industrial (30% women), and biological (35% women) engineering which are all higher than the national average of 19% of bachelor's degrees awarded to women [33]. The way in which women speak about their agency beliefs, both prompted and unprompted, gives a deeper understanding how women view their chosen careers and their impacts. Seeing how engineering is involved in everyday aspects of their lives as well as the potential to make large global changes is important for women in their discussions of engineering. These areas highlight ways to get women interested in engineering as well as empower them through a typically non-traditional career that can address traditional social values of wanting to help people and make an impact. The development of agency beliefs allows individuals to act intentionally against established social structures [15]. These students, especially women, can become empowered to choose engineering as a career despite the lack of women in engineering. Women's discussion of agency beliefs shows the breadth of agency beliefs and illustrates how women describe their beliefs about the potential for engineering to make a difference.

3.2 Identities

When students were asked if they saw themselves as a math or physics person on a seven point anchored scale from "no, not at all" to "yes, very much," all students except for a couple indicated a math identity ($\bar{x} = 5.2$) that was equal to or higher than a physics identity ($\bar{x} = 3.7$). Upon comparison of the means for these questions, a significant difference was found ($p < 0.001$). In the transition from high school to college, a previous study found that developing a physics identity was more important than developing a math identity for both men and women [18]. However, in this data set, only two out of forty-six female students reported higher physics identities than math identities. This finding may be explained by the fact that students interested in STEM careers were pushed toward physics in high school and high school physics curricula focus on applications of science, similar to the way students conceive of engineering [34]. However, when students took physics in college, it was not necessarily as related to engineering as their math courses. Students in engineering are typically required to take twice as many math courses as physics courses in their degree process [35]. In addition, in many engineering programs, math is regularly used in and explicitly related to engineering courses, while physics focuses on theory and common terms like "energy" do not translate across the curriculum [36]. This difference in exposure and focus on math over physics in the post-secondary engineering curriculum may explain the switch for students from a physics identity emphasis for choice of engineering in previous studies [18] to higher math identities in this study.

Additionally, when asked to describe the ways in which they felt like a "math person" or a "physics person," students had markedly different ideas about what it meant to hold a math identity versus a physics identity. Math identities were discussed with a wide variety of rich terms including examples of how students were good at solving problems, able to understand the material, enjoyed the subject, received recognition by others, and how math was connected to everyday life.

Some examples include:

Student 21: *I love working out math problems, seeing how you get an answer, and that there is only one right answer, and a specific algorithm for getting the answer.*

Student 22: *Being able to teach someone else the subject.*

Student 42: *Math just tends to click with me; it doesn't take me very long to solve a problem. If I have seen an example of a similar problem, I am usually able to figure it out.*

Student 6: *Engineering school has opened my eyes as to what math can really explain in the science world. There are so many ways in which scientific topics are modeled through mathematics in order to compute numbers that are extremely close to true value, all through mathematics.*

Physics identities, on the other hand, were discussed in more limited ways. Students spoke about being good at physics, understanding physics, and seeing physics in everyday life. Almost no students spoke about their interest in physics.

Student 46: *The real world makes more sense with a knowledge of physics.*

Student 23: *I understand how forces act on a body, I am good a visualizing things, and I am good at problem solving.*

Student 33: *It helps you understand how to problem solve, such as how much force you need to apply at what angle in order to move/turn/open something.*

Conspicuously, the ways in which students described both their physics identity and their math identity did not include many instances of recognition. Recognition was included a few times when students discussed being a math person, but was never discussed as a part of being a physics person. This lack of recognition experiences in students' narratives may be due to the fact that they have been asked about how they see themselves, and, in this reflection, they do not talk about how they feel others view them. Additionally, while the importance of recognition has been shown, students do not explicitly discuss it. They internalize that recognition into who they see themselves to be through external validation. Because this validation process is initiated from others, students may not cite it in their personal narratives about the type of person they see themselves to be. The lack of recognition in student narratives may also be due to the social positioning of the question as egocentric.

However, when students write about taking on the vital role of feeling like an engineer in identity work, recognition does come out as an important for becoming part of the engineering community and their identity. The engineering recognition responses were rich in detail and students emphasized how they felt they belonged in their community through instances of internalized recognition. In understanding the importance of recognition for identity development, the concept of recognition must be probed explicitly because students are not likely to bring up the concept in self-oriented discussions of who they see themselves to be.

3.3 Community of Practice

An important difference in these data from previous work at the transition from high school to college [18], is the point in the participants' education at which they were collected. Most students were in their second or third year of their engineering studies. In contrast to the earlier surveys, students had been exposed to an engineering Community of Practice and had begun to develop traditionally studied engineering identities. Lave and Wenger described a Community of Practice as:

> *An aggregate of people who come together around mutual engagement in an endeavor. Ways of doing things, ways of talking, beliefs, values, power relations—in short, practices—emerge in the course of this mutual endeavor. As a social construct, a Community of Practice is different from the traditional community, primarily because it is defined simultaneously by its membership and by the practice in which that membership engages* [11, p. 464].

From this perspective, constructing knowledge is an inherently social process and involves being a participant in a community, which comes with normative cultural practices. Students become a part of a Community of Practice as they begin the process of learning what it means to be an engineer. Communities of Practice generate and appropriate a shared repertoire of ideas, commitments and memories. Participants also need to develop various resources such as tools, documents, routines, vocabulary and symbols that in some way articulate and carry the accumulated knowledge of the community. While students may not identify as engineers immediately, they are still participating in a "peripheral" way to the Community of Practice. Learning to perform appropriately in a Community of Practice transitions members from participating "at the fringes" to becoming core members in a process of "legitimizing" participation [11]. One may argue that an individual's identity cannot be formed without "legitimate" participation in a Community of Practice. However, as these students began their college careers, they began to construct knowledge of what it means to be an engineer and how to identify as an engineer as well as practice engineering-related activities. In this process, their engineering identities as a part of this Community of Practice began to develop and interact with previously studied physics and math identities that were so important to their earlier engineering choice. This identity development is situated within an engineering Community of Practice. For example, one student said that she was engineer because she was "in the process of developing the tools to successfully be an engineer."

Because recognition is so critical to students' identity development, understanding how students feel recognized within the classroom is valuable for informing pedagogy. Students' identities in engineering may be fostered by taking advantage of specific formal and informal education opportunities. When asked how they felt recognized as engineers, female engineering students responded in a variety of ways. Many cited design projects, internships, and others recognizing their talent to problem solve as ways of being seen as an engineer. Some examples of specific situations in which recognition as an engineer was internalized by students spoke about freshmen design projects:

Student 2: *During my freshman year, the engineering class worked on group projects. We designed a device to save energy and presented it to peers and faculty.*

Student 24: *In my freshman intro to biomedical engineering class, we had to design an intubation mannequin that met a lot of specifications, and then build a prototype and give an 'elevator speech' to our lab group. My group won, and so we went on to build an entire business plan and present it to the whole class. This meant redesign of a more sophisticated model and looking at markets and calculating return on investment, et cetera. It was a great learning experience, both with regard to engineering and business. I felt recognized when we went on to the final round and got a lot of positive feedback on our prototype.*

Student 33: *I really felt like an engineer during freshman year of college in which an assignment in my statics class involved designing and building a tower out of wooden dowels that could withhold about 20-30 pounds while also being as light as possible. My partner and I were very successful in this project, and actually won the competition as we were the group that were able to actually take the assignment and think outside of the box.*

These students saw more "legitimate participation" in engineering through pedagogy that can be implemented in the classroom. Instead of learning specific content knowledge or doing problem-solving exercises, these students felt like engineers by "doing." These projects involved designing and actually building specific prototypes based on engineering fundamentals. The recognition component of their identity development was realized through presentation or competition of their results. This external validation of their product is the type of recognition experience that students actually internalized and used in their construction of an engineering identity. This finding is consistent with other work that showed that specific learning setting provides resources for the development of subject-related identities [37].

Other students talked about ways they felt recognized as engineers outside of the classroom:

Student 28: *When my sorority was setting up for an event, some other members couldn't figure out how to set up the stage and one said "someone go get [name], she's an engineer, she can figure it out." I felt recognized as an engineer because she explicitly said it, and she also was referring to engineering in a positive way which made me feel like my skills were appreciated.*

Student 41: *I am a Resident Assistant, and among my staff, whenever we have team builders, they always say "The engineer! The engineer can figure it out!"*

When peers saw these female students as a part of the engineering Community of Practice, they felt recognized as engineers. The reputation that they were able to figure out something or fix something based on their chosen career allowed these students to feel like they were engineers and belonged in that Community of Practice. Recognition of students as engineers by their peers falls outside of their Community of Practice but still has significant impact on how students feel a part of their engineering community. As students internalize what others within and without their engineering Community of Practice say about their identities as engineers, their sense of belonging within engineering develops. This finding shows that when students talk about the influences of their peers in feeling recognized as an engineer, it can be students within their major, or friends that they interact with outside of that community.

3.4 Engineering choice

When describing the most important influences on choosing engineering, most students described an interest in engineering, strong performance/competence beliefs and/or interest in math and science, and the influence of family and teachers. The importance of math and physics identities and agency beliefs as measures of students' internal self-beliefs are important for students' choice of engineering. Additionally, the influence of family and teachers in women's choice of engineering was discussed in two previous quantitative studies [38, 39]. Women's physics teachers and, even more than men, their chemistry teacher were important influences on career choice [38]. Additionally, the effects of occupational inheritance from parents and self- efficacy beliefs derived from vicarious learning experiences of siblings which are familial engineers is a significant predictor of engineering choice [39]. Students' qualitative responses triangulate this previous quantitative work. For example:

Student 14: *I liked math and designing 3D models on computers, so it [engineering] seemed like the best fit.*

Student 15: *I have always loved problem solving and the feeling you get when you help people fix something or make something better. Engineering is a perfect way to implement those skills.*

Student 6: *I really, really enjoyed chemistry and math in high school. A career that often came up when discussing* *these topics was chemical engineering. I figured it was probably a good fit.*

Student 34: *[I chose engineering because of] my strength in mathematics, but desire to apply it to more than teaching.*

Student 35: *My dad is a Civil Engineer and I have always looked up to him as my inspiration. My grandfather is also a Civil Engineer and co-owns a company that my dad and other family members also work at. I have always wanted to work with both my dad and grandpa.*

Student 45: *I look up to my dad and my mom's cousin, who both really encouraged me to be and engineer.*

4. Discussion

The connections of CEA that were seen in earlier research were validated and expanded upon by the data collected here. Student narratives of their own identities are inherently ego-centric. When asked to discuss how they feel like a "math person" or "physics person," students spoke about their interest, performance/competence, and/or the connections that they saw between that subject and everyday life. Only a few students who had very strong math identities spoke about how they felt that other people saw them in that way. Recognition as an identity construct takes into account a social aspect of identity formation. Students' identity development in STEM is influenced by the ways in which they interact and participate with people and within a community. It is important in the understanding of identity to take into account how students believe other see them. This factor is more important in predicting students' math and physics identities than either performance/competence or interest alone. Additionally, the concept of recognition is fundamental to a Community of Practice [11]. Human beings are social creatures who have agency in the world around them. Recognition beliefs capture this social aspect by considering what it means to belong and have a sense of community membership. This membership is integral to part of individuals' sense of affiliation or identification with certain communities and does have great impact on feelings of belongingness and ultimately persistence [1, 20, 40]. However, recognition is not a regular part of students' self-constructed narratives about their own identity formation. This result may be due to the self-focused accounts of students' personal narratives or the lack of the metacognitive ability to reflect on how others make them feel a part of a community.

Students who spoke about their identity with respect to interest as opposed to just performance/competence had stronger identities. These narratives mainly occurred in a math rather than a physics context. Students may have associated physics with engineering in high school since physics is typically branded as a gateway course into engineering and may be presented as applied science similar to students' perceptions of engineering. However, students may find college physics to fall short of these expectations. One student documented that he found physics to be a class in which it is difficult to get a good grade, time consuming, or boring, dull, or simply not fun [41]. These experiences may turn off students previously interested in physics as it related to engineering and reduce their perceived physics identities over time. Additionally, the culture and pedagogy of many physics classrooms turn off women to physics [42]. Math, however, is a different community. Research has shown that women taking mathematics courses are taught similar amounts of mathematics and receive grades that are similar to (or better than) those of their male counterparts [43]. Additionally, women currently comprise 43% of bachelor's degrees awarded in math which is more than double the fraction of degrees awarded to women in physics, 21% [7]. These representation differences may be a reflection of the differences in attitudes in these two communities and how students speak about who they see themselves as in math and physics.

Examining how women see themselves to be a physics person and the channels through which that identity is limited can help address the representation issues of women in engineering. Having a physics identity is important for both men and women to choose engineering as a career [21], but women's development of these identities seem to be limited by how they discuss what a physics identity means. Lack of interest and recognition in their discourse points to lower physics identities and possibly lower engineering enrollment. Students who desire to be competent in a subject but do not desire to take on subject-related identities associated with membership in these communities often face difficulties in the subject area and are turned off by the subject [44]. Capturing women's interests and beginning to recognize these students in the classroom may improve their identity, which has been shown to have a positive impact on engineering choice. Additionally, increasing the way in which women are recognized and internalize this recognition in math may improve some of the representation issues for women.

Understanding how women feel recognized in engineering, which is also a significantly underrepresented field, offers some practical findings for pedagogical reform in the physics, mathematics, and engineering classrooms. Women describe recognition experiences as legitimate participation in the community through projects in which they take on a leadership role and experiences in which they make a valid contribution to the knowledge base. Because physics and math are courses closely associated with an engineering degree, these ideas could be incorporated into math and physics curricula with engineering-related projects that include more abstract science and math being learned. This work addresses the research questions by describing how women identify with physics and math.

Women interested in engineering have more complex and varied agency beliefs than previously identified. Agency beliefs in CEA are inherently social, as is identity, and having agency within a Community of Practice allows students to not only craft who they see themselves to be in a community but also imagine their intentional participation within that community. Agency is at once the possibility of imagining and asserting a new self in a community at the same time as it is about using one's identity to imagine a new and different community that is improved through one's own legitimate participation [45]. Many individuals described these beliefs about their future participation in an engineering Community of Practice to improve the world. This empowerment was involved in how students described their reasons for choosing engineering as well as what they wanted to do with their intended careers. The concept of who women saw themselves as in the future, as engineers, was aided and cemented by their beliefs that choosing a vocation in engineering would fulfill their beliefs that they could make a positive change through their own actions. These beliefs may be placed on a spectrum ranging from the broad, global impact of engineering to the specific understanding of how choosing a career in biomedical engineering can improve solutions for a sick mother.

The relationship between identity, agency, and Figured Worlds, of which a Community of Practice is a specific type, has been documented by Holland and colleagues [46]. Figured Worlds are "socially and culturally constructed realm[s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued other others" [46, p. 52]. This definition is an expansion of Lave and Wenger's definition of a Community of Practice as a way to identify social groups on the basis of participation in particular activities or practices [36]. A Community of Practice is a type of Figured World because actors within this group do define their membership by their culturally constructed and accepted practices of dialogue, actions, and values. However, a Figured World also emphasizes the abilities of actors to innovate, improvise and reconfigure the norms, the tools, the practices and all aspects of their social and cultural lives [46]. This work looks at a specific Community of Practice, within engineering, and how students become a part of engineering culture and reproduce community products, but also examines how agency plays a role in participation and change in engineering.

Communities of Practice utilize students' agencies to transform their identities. Their identities, in turn, create possibilities for asserting changes in their Community of Practice through agency. Agency in this conceptualization functions as an agential bridge between identity and a Community of Practice. This concept has emerged in how student describe who they see themselves to be within a context. Students who describe themselves as recognized as engineers (i.e. participation in engineering Community of Practice) speak of how they see engineering as a practical way to make the world better (i.e. agency). This idea, in turn, also feeds into who they see themselves to be and how they describe themselves as engineers (i.e. identity). This agential bridging occurs in how students speak about their recognition beliefs. These developed engineering identities have the potential to empower students (e.g. agency) to change their Community of Practice for the better. This agential bridging may be the mechanism by which students who develop a subject-related identity begin to participate in a Community of Practice. Students form agency beliefs about their chosen careers in nuanced ways and, many students speak of out of classroom experiences as ways in which they form agency beliefs. While students form CEA within a Community of Practice, their emergent agency beliefs also are informed by their Community of Practice and how involved they become. As students become more central players in a Community of Practice, in part through recognition, their ability to envision participation in the community in a meaningful way to change the world outside that community increases. This positive feedback loop between students' CEA and Community of Practice through agential bridging emphasizes the importance of understanding a sociocultural perspective in self-concept research.

Specific examples of how this plays out in student narratives is through the ways in which students describe feeling recognized as engineers. Women describe situations in which others say they are an engineer because they can "fix" or "do" something. Women also felt recognized by being involved with engineering projects or working in an engineering industry. Students also spoke of being prepared to do "real" engineering. The overarching theme of these descriptions is participation in the vocation of engineering. Students who felt that they legitimately participated in engineering felt a part of that community. These students also became empowered in engineering through their participation of seeing themselves as engineers, an example of agential bridging.

This idea of how identities and Communities of Practice are linked is similar to findings by Calabrese Barton et. al on how identities are formed over time [47]. The process of identity formation involves the actions that individuals take and the relationships they form (and the resources they leverage to do so) at any given moment and as constrained by the historically, culturally, and socially legitimized norms, rules, and expectations that operate within the spaces in which such work takes place [47, p. 38]. Identity involves interacting within a Community of Practice with culturally normative behaviors. The negotiation of self-concepts must occur within these spaces which may be supportive towards forming an identity or may deter identity development. Students' agency beliefs are not only a way in which identity formation occurs, but it is the empowerment which allows women to form identities within a Community of Practice that may have normative values and culture that do not promote the identities of underrepresented groups. In turn, agency beliefs can empower students to make change within a Community of Practice to improve the culture for future underrepresented students.

As a theoretical framework, Critical Engineering Agency goes beyond an individual's sense of self as a person whose actions can make a difference to include actions aimed at social transformation which are informed by engineering understandings and practices. The research questions addressed in this study illustrate ways to foster female belongingness in engineering. Women in college engineering identify with mathematics more than physics. In their narratives, they describe their math identities with more weight placed on elements of interest than they do so in physics. Many women describe their career goals in terms of their agency beliefs. The rich descriptions of how students view engineering as a way to make change in the world is more meaningful and nuanced than previous measurements [18]. The breadth of student responses and ways in which women discuss their agency beliefs as well as the connections between identity formation and Communities of Practice create new insight into how agency plays a role in the CEA framework.

Women discussed in a limited way how they formed their agency beliefs. Students who provided unsolicited discussions of agency beliefs spoke about how life experiences impacted their view of engineering as a way to make a positive impact in the world. This paper illustrates that agency beliefs are more central to students' CEA than previously hypothesized. Agency beliefs function as a bridge between students' identity formation and their involvement within a Community of Practice. Communities of Practice have been previously thought to facilitate identity formation, but these student narratives have shown that students connect their vocational community with their already held identities through their agency. The findings of this work deepen the understanding of CEA and how the constructs of identity, agency, and being a critic interplay with students in the context of their past and concurrent educational experiences. This work contextualizes student responses within engineering and gives a deeper understanding of how CEA empowers women to not only choose to pursue engineering in college but remain in engineering once they have begun.

5. Conclusions

The aim of this paper was to highlight ways to foster female belongingness in engineering classrooms. We offer a new theoretical framework, Critical Engineering Agency, to understand students' affective beliefs and how they can be used to retain underrepresented groups in engineering. This theory highlights important ways to change how engineering is taught, especially early on in college. Creating connections in engineering classrooms to how engineering can improve society and relate to "real world" applications can tie into women's agency beliefs. Additionally, feeling a part of an engineering Community of Practice can be developed through authentic engineering experiences as early as the freshman year to promote opportunities for recognition in engineering activities. From the current work, these experiences may include in-depth, problem-based teaching, meaningful engineering design projects that will be implemented, and/or opportunities for co-ops and internships with engineering companies. We hope that our work will encourage educators and administrators to design engineering pedagogy and recruitment materials with students' identities and agency beliefs in mind so as to create opportunities for women to see themselves as engineers. These efforts can improve women's belongingness in engineering and begin to stem of tide of non-persistence of women in engineering.

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Appendix A: *A Priori* Code Book for Critical Engineering Agency

Career Choice

Definition: This code is designed to show what students' desired or undesired careers are and should be able to answer the question, "What are students' (un)desired future careers?" This code includes intermediate careers that students name prior to a terminal career.

Examples: I'm hoping to branch maybe off of geological engineering and kind of go into environmental, but I mean I'm not fully positive that that's what I want to do, but right now that's what my plan is.

Influence on Career

Definition: Captures the external influences of others on students' career choice. This code answers the question, "What/who influences students' chosen career?"

Examples: Going to [country] definitely made me like start to and also my class in high school with [Michael] that made me like just interested into it, and working like at the internship further continued it, and then actually just being in college and experiencing it makes me want to keep going.

Perception of Career

Definition: Characteristics students believe they need to be an engineer. This code answers the question, "What do students think they need to be an engineer?"

Examples: I think that in order to be an engineer, you must have skills such as being creative, intellectual, technical, good at math, etc. You need to be able to think outside the box and work well in groups, as well as by yourself.

Interest (area)

Definition: A person's desire or curiosity to think and learn about an area (e.g. mathematics, physics, engineering, STEM, etc.). The code answers the question, "Is this student interested/uninterested in [area]?"

Example: I like chemistry as a whole so like there's not like a particular, because like each new thing I just like learning more about it. I like being in AP Chem now because we like go more into depth of where like chemistry was more just like on the surface.

Performance/Competence (area)

Definition: People's beliefs about their ability to understand (competence) or excel (performance) in an area (e.g. mathematics, physics, engineering, STEM, etc.). This code should be able to answer the question, "How well does a student feel that s/he can understand and do the tasks required?"

Example: I'm in pre-calculus but like I mean I still get it (competence), like I get good grades in that (performance), too.

*Note: students speaking of others coming to them for help is coded as Performance/Competence - (area). This concept loaded onto Performance/Competence rather than Recognition in quantitative work [15].

Recognition (area)

Definition: How people perceive how others view them in relation to an area (e.g. mathematics, physics, engineering, STEM, etc.). This code should be able to answer the question, "Does the student feel that others see them as the type of person who does [area]?"

Examples: They [friends] all know that I want to do the chemical engineering and they all know that I, my friends tease me about it, I go yeah, you're a chemistry nerd. I'm like whatever. But so I mean, my friends realize that I like it.

*Note: students speaking of others coming to them for help is coded as Performance/Competence—(area). This concept loaded onto Performance/Competence rather than Recognition in quantitative work [15].

Identity (area)

Definition: How individuals see themselves based on their perceptions and navigation of everyday experiences in a given context. This code answers the question, "What kind of person does the student see/not see themselves as?"

Example: I still think of myself as a like a math-based person it's just been a lot harder [to get an "A" in math].

Agency Beliefs

Definition: students' perception of their ability to change their world through everyday actions and their broader goals. Students' agency beliefs involve how students see and think about STEM as a way to better themselves and the world. This code should be able to answer the question, "Does a student value science/ engineering for action/change in the world in direct relation to his/her life?"

Example: I just wanted to go there to help people out. So, I mean it [bringing water to country] taught me just like once again to like be thankful for what I have, and just um that you should always help people, and, and then they liked helped me out with they changed me and made me a better person, and like yeah. It's a really neat thing.

Appendix B: Open-ended Survey Questions

What year are you in college?

What is your current major?

What was your intended major when you entered college?

Has your declared/intended major changed since you started college? If so, why?

Please describe the three most crucial influences (people, experiences, school-related subject, etc.) on your career choice in order of most to least important.

Please describe the characteristics (e.g. social, intellectual, technical, and other skills) needed to be an engineer.

Do you see yourself as an engineer (anchored scale from "No, not at all" to "Yes, very much")

Describe three ways in which you see yourself as an engineer?

What do you want to do with a career in engineering?

Describe a scenario/experience in which you felt recognized as an engineer. (If you haven't had a scenario/ experience where you have been recognized as an engineer, state so.)

Describe three ways in which science and engineering can impact the world.

Describe three ways in which science and engineering can impact your life personally.

Do you see yourself as a math person? (anchored scale from "No, not at all" to "Yes, very much")

List three ways in which you see yourself as a math person.

Do you see yourself as a physics person? (anchored scale from "No, not at all" to "Yes, very much")

List three ways in which you see yourself as a physics person.

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