”Because I’m not always constantly getting everything right”: Gender Differences in Engineering Identity Formation in Elementary Students (FUNDAMENTAL)

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I Introduction

Engineering is a relatively new addition to elementary school classrooms, a result of its inclusion and elevated importance in the *Next Generation Science Standards* (NGSS) [1]. Within the nascent field of pre-college engineering education, the ways in which elementary engineering experiences may support the formation of engineering identities in young children are not well understood [2]. What is known about formative experiences in engineering is that participation tends to be gendered [3], with girls and boys engaging in and reflecting on engineering activities in different ways. This paper focuses on identity, as developing a strong engineering identity, or sense of belonging in engineering, is essential to pursuing and persisting in the field. Participation in engineering outreach programs is widely seen as an opportunity for youth to ignite and increase formative aspects of engineering identity. As early as elementary school, youth evaluate their experiences, interests, and successes to make choices about possible futures [4]. Although these early experiences and choices influence future participation in, pursuit of, and persistence in engineering, studies of engineering identity development have concentrated on undergraduate and high school learners. In this study, we investigate how students' characterization of their own engineering participation might provide early indicators of their future engineering identity by identifying common emergent themes in the ways that students talk about their experiences.

A. Conceptual Framework

Engineering Identity. Within the current research literature, identity is constructed in different ways. In engineering contexts identity has primarily been studied in undergraduate students and adults, in the contexts of career choices and retention of students within programs [5]. Sfard and Prusak [6] propose an idea of identity that is shaped around narratives. They posit that identities are the stories individuals and the people around them tell about themselves. Identities have many facets, authors, and audiences. Self-perpetuating narratives of success and failure shape identity. Institutional narratives, such as success and failure in the school setting, are particularly influential over the way a student may think about their identity [6]. Often, youth have trouble defining what it means to be an engineer. Verdin et al. [7] found that only high schoolers who personally knew people in the engineering profession could answer confidently when asked what it meant to be an engineer. Most students answered with difficulty that engineers are people who think differently from other people and have an elite level knowledge. There was a prevailing belief among the students that someone classified as a "STEM person" possessed a specific set of characteristics. These characteristics included being able to easily learn and understand the material (i.e., to have it come naturally), being perceived as smart, and being interested in STEM. Engineers were believed to need skills in math, science, and physics and to have the ability to think creatively. Specific ideas of who can be an engineer make doing engineering seem inaccessible to individuals who don't think they fit the characteristics. The narrative that engineering skills come naturally to a select few as opposed to the narrative that engineering skills can be learned and acquired through experiences can discourage youth and work as a form of gatekeeping for underrepresented groups in STEM fields, such as girls, who are reported to have lower confidence in their STEM abilities than boys [8]. Some studies found that learning engineering in a classroom setting influenced students to apply classroom values, such as compliance and quantitative success, to their engineering activities [9], [10]. This clashing of engineering and classroom values made students more hesitant to fully explore the potential of in-class engineering experiences, for fear of a collaboration causing disruption.

In this study, we draw on Godwin and colleagues' [8] constructs of engineering identity formation in post-secondary students to understand possible aspects of identity formation in younger students. This framework consists of three primary constructs that impact engineering identity: *interest*, *performance/competence*, and *recognition*. The first of the three constructs, *interest*, attends to prior findings that students' interest in STEM subjects, such as mathematics and physics, appears to be formative in those who pursue engineering and develop engineering identities. The second construct, *performance/competence*, refers to the described perceived performance or competence of an individual learner, rather than objective and measured performance/competence. A student's engineering identity is affected by their belief in their own abilities. Believing in one's own knowledge and abilities (which are both encapsulated in the construct) in engineering provides a strong basis for seeing oneself as an engineer (i.e., you do what you believe you can and you become what you do). Performance/competence is dependent on how the student defines success and capability in engineering. The third and final construct is *recognition*, which focuses on students' perception of how others view them as engineers. This can manifest as people perceived as experts (teachers, engineers, ambassadors, or role models) directing affirming comments towards students or explicitly telling them they could be engineers [11], or in more subtle ways, like peers seeking one's help with engineering.

Gendered Engineering Identity Development. Though this paper primarily utilizes Godwin and colleagues' [8] work to conceptualize our emergent findings, other researchers have created frameworks to focus on specific populations of students. Capobianco and colleagues et al. [2] focus on the formation of engineering identity in female students, identifying girls' sense of academic identity, school identity, occupational identity, and engineering aspirations as shaping their engineering identities, with academic identity and engineering aspirations being the strongest influencers. Their findings indicate that of those categories of identity, academic identity and engineering aspirations had the strongest influence. Buontempo et al. [12] introduce the idea of "attainment value" which is connected with students pursuing subjects because they feel that the subjects have a specific value to them. This can be applied through a gendered lens, as boys and girls place different values on different things. For example, girls place a large value on helping people in future occupations and are often drawn more to biological sciences than "hard sciences," such as physics, than boys are [13]. Girls have reported finding satisfaction in the collaborative and altruistic aspects of science [14]. Aspects of the learning environment that might discourage them from pursuing STEM are a lack of female role models and the internalization of failure. Godwin and colleagues found that women have similar performance in engineering to boys, but lower confidence in their skills [8]. Moote et al. [15] found gender-linked disparities in career aspirations in engineering, positing that this disparity shows how the traditional branding of engineering as masculine is still greatly affecting students' relationships to engineering. Some studies have found instances of gatekeeping in engineering, where young boys try to assert that engineering is not a female space, taking control of projects and not collaborating with female group members [3], [15]. Girls must navigate difficult-to-access, traditionally male spaces, and reconcile performance of engineering and feminine identities, which are considered socially incompatible, in order to construct an engineering identity [15]. Studies about identity in engineering education have typically focused on secondary or post-secondary students. In this study, we utilize Godwin and colleagues' [8] framework on identity development in secondary students and elementary students' reflections on their participation in engineering outreach to explore how identity may develop in elementary students.

Role Models in Engineering. One proposed method to support engineering identity development in young girls is through outreach programs that explicitly put female engineers or engineers-in-training in elementary classrooms, as is the context for this study. Through engaging elementary students in engineering design challenges, the Tufts STOMP program aims to support youth to practice engineering design thinking, hone their creative problem-solving skills, develop and sustain a sense of themselves as capable engineering learners and engineers, build an affinity toward engineering, and envision engineering study and careers as possibilities for them. In order to support building trusting relationships between students and ambassadors, the ambassadors work with the same classroom each week throughout a semester or academic year. When students are designing, ambassadors support them to identify successes, to improve solutions through iteration, and to persist through frustration or failure. In addition, the ambassadors make an effort to connect with students on multiple levels. Ambassadors share examples of their own engineering projects with students and talk about what they enjoy and find frustrating in engineering. Ambassadors listen to students and respect their individuality. As youths' conceptions of who can be an engineer are possibly influenced by the gender imbalance in professional engineering [17], this program aims to introduce students to female engineering students. Each of these focal classrooms worked with at least one female engineering student to ensure that all students had the opportunity to get to know a female engineer.

Research Questions. In this study, we explore influences on elementary students' engineering identity by first exploring the experiences which mediate their interest and competence in engineering. We specifically ask: What do students' descriptions of their interest and competence in engineering tell us about their developing engineering identity?

1. How do students describe their engineering experiences through the lens of interest and performance/competence identity constructs in engineering?
2. How might negative descriptions of performance/competence in engineering mediate development of engineering identity in girls?

II Methods

Context. This study is situated within the context of a university-based outreach program located in a large urban city in the northeastern United States. The STOMP program aims to increase engineering participation of elementary-aged students using classroom activities. Undergraduate engineering students, referred to as "ambassadors," are sent out in teams of two to classrooms in the greater urban area once a week for 12-18 weeks during the school year. During each visit, they lead an hour-long session designed to encourage creativity and the use of the engineering design process among elementary-age students. Examples of student activities include model rocket-building, using the program TinkerCAD, creating parachutes and balloon-powered vehicles, and students utilizing Makey Makey software to make their own video games. Due to well-documented gender disparities in engineering, each classroom was assigned at least one female ambassador to serve as a potential role model for female students, as part of a larger research project examining role models in the STOMP program and female students' relationships to engineering.

Study Participants. The participants in this study were 76 fourth and fifth grade students from seven classrooms in four suburban schools in the northeastern United States. The students in the study all participated in the focal outreach program during the 2018-19 academic year. Participants were nearly evenly split in gender (39 females; 37 males) and represented an ethnically diverse group (38% White, 21% Hispanic or Latinx, 11% African-American, 11% Asian, 5% Multiracial, 0% Native American, 0% Native Hawaiian, and 0% Pacific Islander; 15% declined to provide a racial or ethnic identification) Families identified the gender of participating students on study intake forms by marking pre-selected options including male, female, nonbinary and a write-in option. Out of the 76 students, all who chose to self-identify selected either male or female; no one selected any other options. Students whose gender was not indicated on intake forms were assigned gender by members of the research team based on personal pronouns used for and by those students in the classroom. All names reported here are pseudonyms.

Sources of Data. As part of the larger project in which this study is embedded, consenting students from focal classrooms were video recorded during their classroom activities, and also interviewed about their participation at the end of the semester. The recorded and transcribed interviews are the primary sources of data for this paper. During the semi-structured one-on-one interviews, students were asked approximately 20 questions regarding interest, identity, self-efficacy, and their relationship to their undergraduate ambassadors. These interviews typically lasted 10 - 20 minutes. In this study, we focus on two questions asked, in which students rated their enjoyment and perceived success in engineering: 1) Think about yourself doing engineering in STOMP. On a scale of 1 to 10, with 1 being the lowest and 10 being the highest, how much do you like doing engineering? and 2) Think about yourself doing engineering in STOMP. On a scale of 1 to 10, with 1 being the lowest and 10 being the highest, how successful are you in doing engineering? These questions were chosen because the answers gave insight into the ways the students were starting to see themselves in relation to engineering. We used *enjoyment* (Question 1) as a proxy for the construct of *interest*, while we used *success* (Question 2) as a proxy for the identity development construct of *performance/competence*. The third construct of *recognition* was not directly addressed in any of the interview questions, though some student responses attended to it. However, due to the limited responses related to this construct, we did not make it a focus of our analysis.

Data Reduction and Analysis. We focused our analysis on students' answers to the two questions stated above, segmenting answers into units of analysis we refer to as talk segments. These talks segments are bounded by shifts in focus of the student's talk [18]. While students rated their enjoyment and success on a numeric scale, initial statistical analysis of those ratings indicated that differences were not statistically significant for gender differences. For this reason, we limited our analysis to the reasons given by the students for their chosen ratings. Student responses were analyzed in multiple cycles of coding by members of the research team using a combination of Excel spreadsheets and the analytical software, Dedoose. In the first cycle of coding, talk segments were inductively coded with emergent descriptive codes [19] as well as descriptive codes indicating generally positive or negative tones of student responses. These codes were further refined in a second cycle coding process through the development of pattern codes based on Godwin and colleagues' [8] framework of identity constructs and grouped under the following pattern codes: *interest, performance/competence,* and *recognition.* Agreement was reached on the assignment of talk segments to construct codes through constant comparative analysis [20]. We then drew on mixed methods to further understand emerging patterns in student responses by utilizing gender descriptors to quantify talk segments [21].

III Findings

We will first share our general findings with regard to how student responses in the end-of-program interviews aligned with Godwin's three primary identity constructs. Then, we will share categories of responses that emerged as indicators of formative differences between the conceptualized experiences of male and female students, which we will refer to as boys and girls, in deference to colloquial terminology for the gender of children. Finally, we focus on the substance of student talk to understand the differences we see in how girls and boys characterize their own performance and competence in engineering activities and how those characterizations might be consequential to development of engineering identity.

During our analyses, we first looked for the frequency of student talk segments within each of the three identity constructs, including how the frequency of talk segments differed by gender (see Figure 1). Of the three identity constructs, more talk segments were identified as being related to the constructs of *interest* and *performance/competence* than as being related to the construct of *recognition.* This was likely due to the nature of the questions asked and the characteristics of the construct of *recognition*. Focusing then on the two constructs that occur in this data at higher frequencies, we see nearly equal frequencies of talk segments between boys and girls under the *identity* construct, and a slightly larger difference between genders under the *performance/competence* construct, with 85 of 143 talk segments regarding performance or competence spoken by girls.

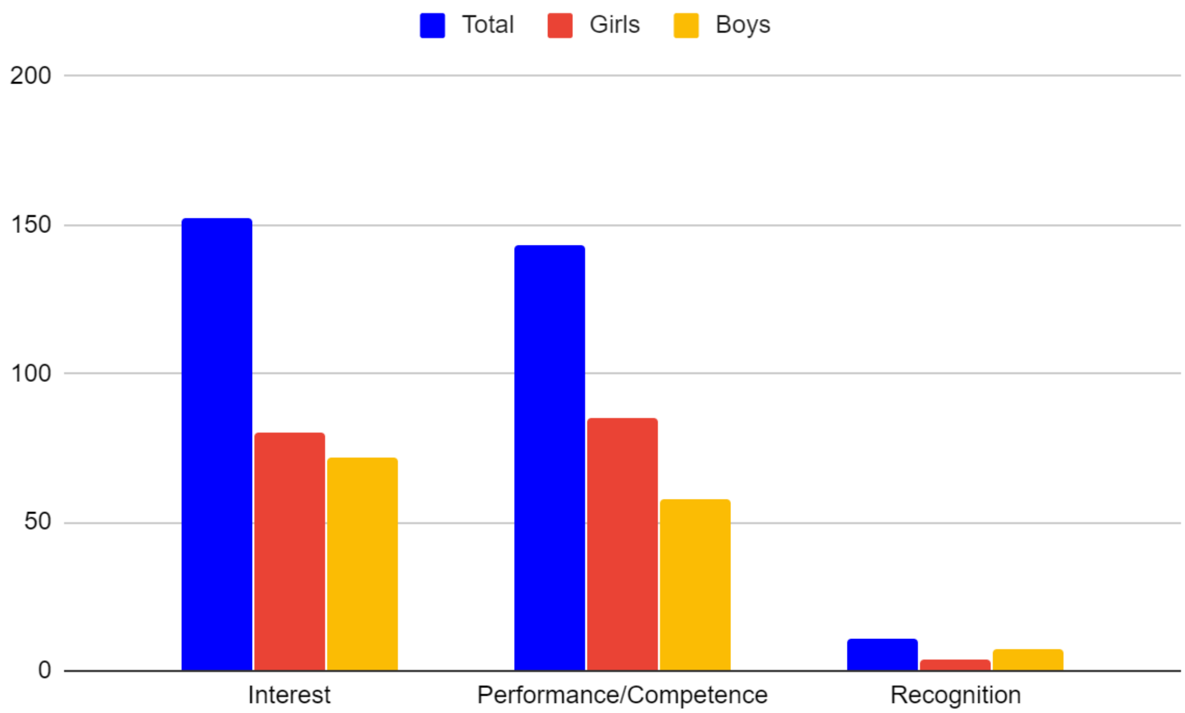

Figure 1. Frequency of Identity Constructs in Student Interview Responses, by Gender

We then focused our analysis on the frequency of positive and negative language in student talk segments, for the constructs of *interest* and *performance/competence*. Overall, student talk around their interest in engineering tended to be more positive, while talk about their own performance or competence in doing engineering tended to be more negative. When we consider these differences in positive and negative talk broken down by gender, talk about students' interest in engineering remained majority positive across both genders, with boys being slightly more positive overall than girls (See Figure 2).

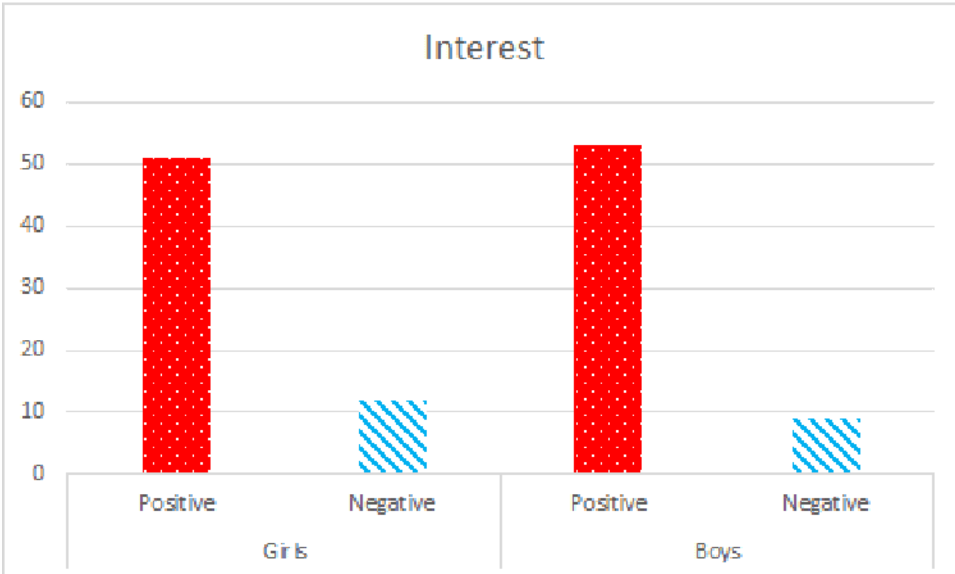

Figure 2: Frequency of Positive/Negative Student Talk by Gender - Interest

However, when we looked for segments of positive or negative talk around students' performance/competence, when broken down by gender, we saw a notable difference between how boys talk about their performance/competence and girls' responses to the same prompts (See Figure 3). Boys, when asked how successful they felt doing engineering had an equal number of positive and negative talk segments. However, the girls' responses were markedly more negative, with 40 of 64 (63%) talk segments identified as negative.

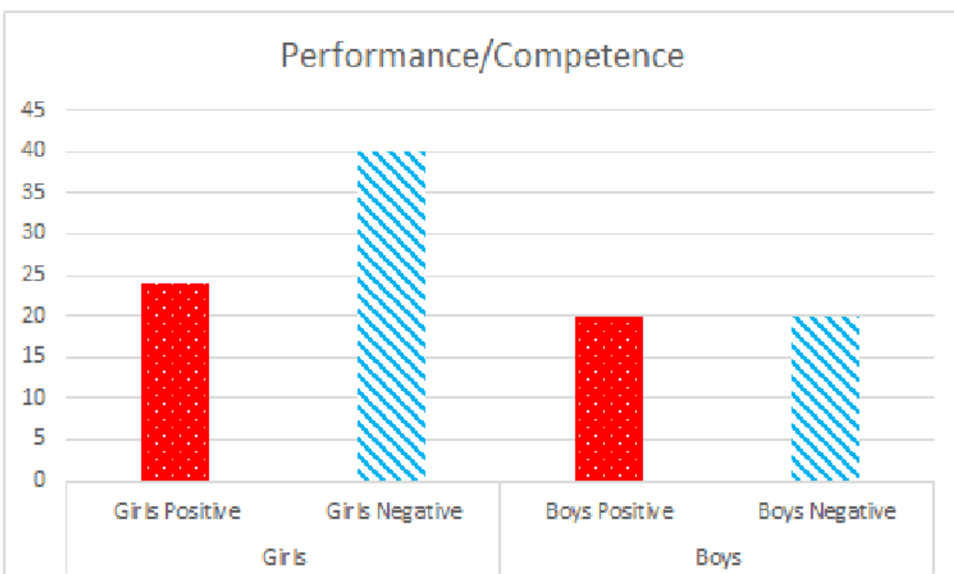

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Figure 3: Frequency of Positive/Negative Student Talk by Gender - Performance/Competence

Based on these observed differences in how students of different genders used positive and negative language, we further narrowed our analysis on the construct of performance/competence due to the notably higher frequency of negative talk segments from girls. Within the construct of performance/competence, there were 15 inductive, descriptive code categories for segments of student talk. Within this set of descriptive codes, we saw notable differences in the frequency of negative talk as compared to positive talk under four of the codes: *working with others*, *knowledge of what action to take, recognition of mistakes,* and *working product.* In Figure 4, we see how, with the exception of when girls talk about their performance or competence when working with others, their talk is more negative than positive for all descriptive codes. In two categories, such as when they talk about knowing what action to take or when they are discussing mistakes, all of the girls' talk is negative, with zero instances of positive talk. While boys also only talk about their mistakes in negative terms, they mention mistakes only rarely (N=2). Boys also differ from girls in the category of *working with others* and when talking about their *working products*. Boys generally speak positively about working with others and have nearly equal positive and negative talk with regards to their working product. Like girls, however, boys also speak primarily negatively about their knowledge of which actions to take during their engineering activities.

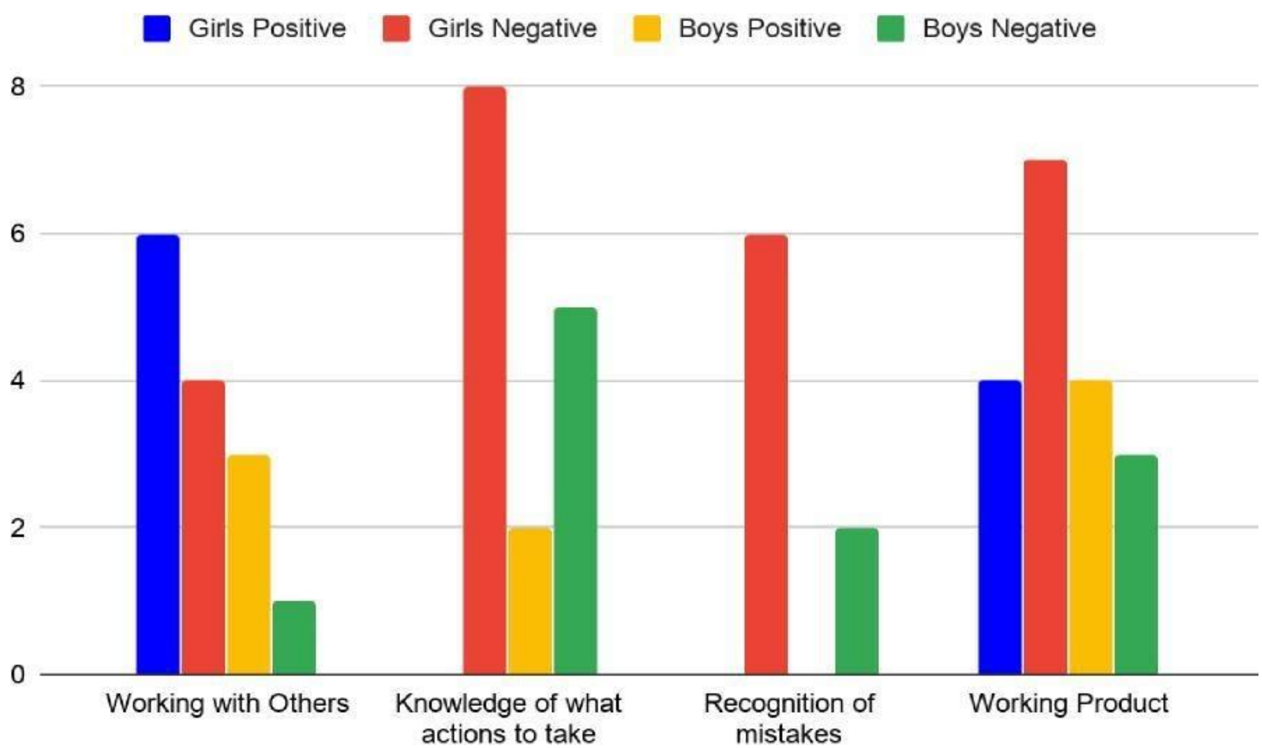

Figure 4: Frequency of Student Talk by Child Code for Four Child Codes of Interest

By analyzing frequencies of positive and negative student talk, differentiated by gender and aligned to constructs around identity, we were able to identify specific aspects of student experiences that might be inhibiting or negatively affecting girls in their engineering identity formation. In the following section, we turn to our analysis of the substance of the talk segments to understand how students describe their experiences in positive and negative ways.

Emerging Patterns in Negative Student Talk: Here we further our analysis within the construct of performance/competence, specifically the gendered differences in how girls and boys describe their participation. Within this bounded analysis, we identified four categories in which boys and girls described their participation differently but focus on the two categories which show the greatest disparity between positive and negative comments across genders: *knowledge of what actions to take* and *recognition of mistakes*.

When looking across student's responses including talk about *knowing what actions to take*, we found that girls most often expressed that they were confused and were unsure of what their next steps were, with statements like: "sometimes I get like confused or something in engineering" (Johanna, Interview), "sometimes I just don't know how to solve it" (Amelia, Interview), and "...sometimes I totally don't know what to do because I just forget what to do..." (Victoria, Interview). We see these types of statements, all of which we identified as negative, as indicating that these girls do not feel confident in their ability to figure out a solution to the engineering challenge at hand. Specifically, we see a pattern in girls feeling like they need to know what the next "right" step is before moving forward. By comparison, boys' talk segments identified as negative in this category, while also indicating points of confusion, tended to describe how they worked through confusion towards creating a functioning prototype. For example, below we see Liam reflect on how he thinks in moments of uncertainty, during the design process:

> I mean because I feel like I'm usually pretty successful but I do have...these moments where I'm like, "Well, what am I supposed to do? How am I supposed to do this thing?"...I mean, having those moments can still lead to being successful, ...but it's not being successful in itself. It's quite the opposite...I mean like when something happens, I get all, "What am I supposed to do about this?" You could still turn that around, but that turn it around part is the part that makes it be successful, not the moment where you're stuck. (Liam, Interview)

These emerging patterns in the ways that girls reflect feeling in moments of uncertainty suggest that they are blaming the feelings of uncertainty on their self-perceived lack of performance or competence in engineering. Phrases or words like "I just don't know" or "I just forget", combined with the persistent use of "I" statements indicates that girls are internalizing blame for not knowing what to do next. This idea is supported by the utter dearth of positive talk by girls (N=0) in the category of *knowing what actions to take*.

In the second category, *recognition of mistakes*, we find that all of the responses given by students of both genders were framed in a negative manner. Among girls' responses, we find evidence that they believe that failure in engineering activities is due to their own mistakes, whereas when boys reflected on how projects did not work, they attribute the failure to external causes. For example, we see Melia saying; "Because I mess up a lot and sometimes it doesn't go well" (Melia, Interview) and Deedee attributing her magnetic levitation car's failure to float as being caused by her mistakes, "I told you how I failed. I put the magnets on the wrong side and then it was sticking to the ground instead of floating...and, a lot of times, I make small mistakes and then I can't go back to fix them sometimes" (Deedee, Interview). Whereas, in boys' reflections, we see statements such as "Whenever I'm alone, it's always successful, but when we're doing group projects, my group is always last...like last as in [ours was] the worst" (Julian, Interview), and "...it's basically like [the prototypes] would fail and I would try to figure out the problem...” (Ben, Interview). As with girls’ talk around knowing what to do next, in this category of recognition of mistakes, we see girls using language indicating that they are internalizing the blame; in other words, they are the cause of mistakes. This, in contrast to the boys’ talk, where they externalize the blame, as with Julian reasoning that it was the challenge of working in a group that caused mistakes and product failure, or as with Ben’s use of the word “they”, referring to his prototype failing.

While we have highlighted here the ways in which girls negatively reflect on their performance or competence within certain aspects of engineering, we do also see instances where they speak positively. Unfortunately, within the two categories we focused on above, *knowledge of what actions to take* and *recognition of mistakes,* we identified zero positive talk segments by girls. But within the other categories, we do see examples of positive talk by girls. For example, we see Josie speaking positively about failure and persistence, “It took a couple tries, but eventually we got it. Then we did it again and it failed, and we kept trying...[and] we eventually got it right” (Josie, Interview). In a similarly positive and resilient tone, we see Vivian reflecting, “Like even if it doesn't go well on the first try, if it goes well on a few tries after, you can use your mistakes on that one to make it better the next time” (Vivian, Interview). In both of these examples of girls’ positive talk, we see them using language indicating that they are not blaming themselves for failure in the design process, but rather are positioning failure as something external to themselves that can be attended to.

While not conclusive, we find these emerging patterns of talk to be illuminating in developing our understanding around aspects of participation in engineering activities that may be affecting students’ interest in, and feelings about, their performance or competence in engineering activities. In particular, these patterns of student talk lead us to question what messages students are hearing, how they internalize those messages through engineering experiences, and how these experiences support the development of engineering identity.

IV Discussion

The implications of the gender disparities we see in our data is that girls and boys are internalizing different messages through engineering experiences in ways that are potentially inhibiting girls from developing a positive engineering identity, which in turn will likely inhibit them from pursuing engineering as a career. We know from prior research that development of an engineering identity is critical in supporting and encouraging youth participation in future engineering experiences [5], [7] and so focusing on questions around how and in what ways early engineering identity forms is critical. We know from previous research that girls and boys experience engineering in different ways [3], [22], but don’t yet understand what specific aspects of the learning environment might be affecting these gendered ways of participating and how those might affect engineering identity development. As early as elementary school, we see gender differences in participation [16] which suggests a need for attention to practices and experiences which promote equity in engineering participation and identity development. How do we design elementary engineering outreach activities to support positive engineering identity development across all genders? For instance, we propose that, given the student reflections we share above, the following aspects of the learning environment may have consequences for engineering identity development: type of engineering activity, ambassador teaching practices, organization of the social context of participation, and classroom norms of participation. It may also be necessary to consider different needs and values between genders. While we have seen that boys and girls engage with engineering in different ways, all genders still have the potential to be successful in engineering but learning environments must be structured to appeal to and support all genders [13]. Spaces that are hostile to female engineers perpetuate the barriers that prevent girls from seeing themselves as engineers, as male engineers pick up on these messages and act as gatekeepers [16]. However, working to make engineering spaces more accessible to girls can also benefit all students, as girls can work to make these spaces more acceptable to their values and learning methods [13].

Another theme that we saw emerging through the student talk is the fluctuating definition of success. While the engineering ambassadors in STOMP are trained to emphasize that success is found through persistence and design iteration, students know success in the classroom is measured by doing things correctly and following instructions. This raises the question: how does a student know if they have succeeded if they are encountering conflicting messages? In our work, we saw these two definitions clash in the students' answers, showing that they felt conflict between the two definitions. As the classroom definition of failure is part of the engineering definition of success, it is understandable that these two ideas would be in conflict with each other. In cases like these, it is important to think about the messages that are being delivered to students and how such messages are influencing students' relationships with their emerging engineering identities. This is especially important when considering gender differences in engineering because of pre-existing gendered behavioral expectations in classrooms. Gendered classroom values and norms of participation can subtly add additional barriers to girls' participation in engineering. It is important to ask; how do we support girls in engaging in authentic engineering activities in ways that align with classroom norms of participation? Alternately, do we explicitly work to change typical classroom norms of participation to align with authentic engineering learning experiences? As we move forward with engaging children in authentic engineering activities, these are aspects of participation that are important to consider.

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