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STEM Roles: How Students' Ontological Perspectives Facilitate STEM Identities

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Abstract

Educational researchers have explored the importance of performance, recognition, and interest in establishing and maintaining a STEM identity. Research has also demonstrated that the ways students describe themselves and how they participate in STEM communities can provide insight into their role identity salience; however, there has been little work to explore the ontological beliefs of students about STEM people and how this influences their ability to see themselves as possessing a STEM identity. This research explores the ontological beliefs of high school students, with specific attention to the ways in which they describe what constitutes a math person, science person, physics person, or engineer and how these descriptions influence their ability to take on these role identities.

Keywords

identity, ontology, STEM pathways

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STEM Roles: How Students' Ontological Perspectives Facilitate STEM Identities

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Abstract

Educational researchers have explored the importance of performance, recognition, and interest in establishing and maintaining a STEM identity. Research has also demonstrated that the ways students describe themselves and how they participate in STEM communities can provide insight into their role identity salience; however, there has been little work to explore the ontological beliefs of students about STEM people and how this influences their ability to see themselves as possessing a STEM identity. This research explores the ontological beliefs of high school students, with specific attention to the ways in which they describe what constitutes a math person, science person, physics person, or engineer and how these descriptions influence their ability to take on these role identities.

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Introduction

There is a need to increase participation in science, technology, engineering, and mathematics (STEM) fields to develop the next generation of qualified STEM professionals (Olson & Riordan, 2012). This need has prompted many initiatives to garner more interest in STEM by younger populations. This group includes, but is not limited to, high school students. Scholars have long since suggested that students' identity plays a pivotal role in their decision to pursue careers in STEM; however, very few studies have investigated how students come to understand what constitutes a math person, science person, physics person, and an engineer. Students rely mainly on mathematics and science (specifically physics) experiences to make engineering choices (Godwin, Potvin, Hazari, & Lock, 2016). It is vital to understand how students' perceptions of what it means to be a math and/or science person are related to their perceptions of engineering and how their perceptions foster or limit access to engineering pathways.

Capobianco, Diefes-Dux, Mena, and Weller (2011) explored grade school students' conceptions of engineering and determined that there "is a recurring message that engineering is not 'for everyone'" (p. 306). In addition, a study by Fralick, Kearn, Thompson, and Lyons (2009) of 1,600 middle school students' pictorial representations of engineers and scientists found that a high percentage of students depicted engineers as people who do manual work in an outdoor setting 32.1% versus 14.7% for indoor setting, while scientists were depicted as working indoors 65.7% versus 7.1% outdoors. Additionally, most drawings of engineers were white and male and depicted the individuals driving trains, fixing cars, or working on the line in a factory (Rynearson, 2016). These findings highlight students' misconceptions of what it means to be an engineer. These stereotypical views of engineers may hinder students' abilities to understand and accurately

describe what it means to be an engineer and their abilities to take on an engineering identity in the future, limiting potential career pathways.

Prior to a post-secondary education, most students have little to no formal engineering coursework or informal exposure to engineering practice; although, this trend is changing with the Next Generation Science Standards and growing engineering formal and informal programming (Bybee, 2014; National Academy of Engineering and National Research Council, 2009). Often high school students who intend to major in a variety of STEM fields take the same mathematics and science courses in their pre-college education, regardless of future intended major. A lack of direct engineering experience makes the development of an accurate engineering ontology prior to college more difficult than for other science, technology, and mathematics disciplines, such as biology or chemistry, which offer at least some direct, explicit experiences for students in high school (Fleming, Engerman, & Williams, 2006; Marra, Rodgers, Shen, & Bogue, 2012; Seymour & Hewitt, 1997).

Most students decide to choose an engineering career pathway in high school. A study of 6,860 students' engineering career decisions found only 280 were interested in engineering careers at the beginning of high school (Cass, Hazari, Sadler, & Sonnert, 2011). The largest increase of students interested in engineering careers occurred during their high school years, with 81% of interested students indicating a desire to choose engineering careers by the end of high school. We acknowledge that students become interested in STEM in general much earlier than high school; however, high school is a particularly valuable time to understand how STEM-interested students may choose or not choose engineering. Because students rely mainly on mathematics and science experiences to make engineering choices, it is vital to understand how their perceptions of what it means to be a math, science, and physics person as well as an engineer are related to their perceptions of engineering and their perceived access to this career pathway.

Ontology Supports Identity Development

Students' identity plays a pivotal role in their decision to pursue careers in STEM; however, very few studies have investigated how students come to understand what it means to be a STEM person or students' ontologies. Students' identities fundamentally shape their pathways into STEM careers, especially engineering. Identity involves not only how students perceive themselves but also how they situate themselves and are situated by others (Gee, 2000). The importance of identity development to learning and career pathways has been well established in the spaces of science, physics, mathematics, and engineering by many scholars in education (Brickhouse, 2001; Brickhouse, Lowery, & Schultz, 2000; Capobianco et al., 2011; Carlone, 2003; Grootenboer

& Zevenbergen, 2008; Hazari, Sonnert, Sadler, & Shanahan, 2010; Shanahan & Nieswandt, 2011).

Specifically, Hazari and colleagues (2010) established a physics identity instrument measuring students' belief of their own performance/competence (i.e., students' ability to achieve good grades and understand concepts), recognition (i.e. by peers, parents, teachers as the kind of person that can do a particular subject), and interest in the subject. These measures of identity strongly correlated with students' self-reported likelihood of choosing a physical science career. Another study using similar measures to Hazari and colleagues (2010) but with a mathematics focus found that these measures also predict a choice of mathematics careers (Cribbs, Hazari, Sonnert, & Sadler, 2015). Both of these studies emphasize the importance of identity to students' career pathways.

In the context of mathematics, the development of identity has been recognized as essential for framing knowledge, skills, habits, attitudes, beliefs, emotions, dispositions, and broadly "who the student is" (Allen & Schnell, 2016; Grootenboer & Zevenbergen, 2008). "Identity has been employed to try and bring about greater understanding of learning mathematics, and perhaps provide some insights into how the perennial issues facing mathematics education may be addressed" (Grootenboer & Zevenbergen, 2008, p. 243). Similarly, the authors of the book *The Impact of Identity in K-8 Mathematics Learning and Teaching* defined mathematics identity as "the dispositions and deeply held beliefs that students develop about their ability to participate and perform effectively in mathematical contexts and to use mathematics in powerful ways across the contexts of their lives" (Aguirre, Mayfield-Ingram, & Martin, 2013, p. 14). This quote emphasizes the use of mathematics in students' everyday lives as a powerful method towards aligning students' identity development with mathematics.

Other scholars have explored the ways in which students speak about the various STEM disciplines, coursework, and themselves to better understand STEM achievement, career selection, and, in some cases, success and persistence in these fields (Blaisdell, 1998; Brickhouse & Potter, 2001; Cech, Rubineau, Silbey, & Seron, 2011; Hackett, Betz, Casas, & Rocha-Singh Indra, 1992). The importance of learning in the science context (situated learning), classroom participation, recognition, and performance to the development of salient and resilient STEM identities has been well established (Brickhouse et al., 2000; Brown, 2004; Hazari et al., 2010; Johri, Roth, & Olds, 2013). The interactions, meaning, and knowledge gathered from communities provide a pathway for students to construct their identities, "or who they are and wish to be, in relation to these communities" (Aschbacher, Li, & Roth, 2010, p. 555). Studies have also found that parents, teachers, peers, and classroom experiences often contribute to the development of students' perceptions of STEM fields (Christensen,

Knezek, & Tyler-Wood, 2014; Knezek, Christensen, & Tyler-Wood, 2011; Wang, 2013). These ways of understanding the nature of what it means to be a STEM person or their ontologies can either foster the development of a STEM identity in students or discourage them. In other words, students' beliefs or perceptions of a field can either support their claim of being or becoming a STEM person or serve as a barrier to becoming a STEM person. Students' internalization and positioning as these kinds of people in these roles (i.e., a math person, science person, physics person, and an engineer), their identities, can have a significant positive influence on career pathways. In this study, we focus on how students describe STEM ontologies to better understand how students conceptualize these roles and how those ontologies influence their perceptions of who can take on these roles (e.g., themselves and their peers).

Situating the Current Study

Literature suggests a link exists between students' beliefs, achievement, and persistence; however, the intricacies of how students' ontologies—ways of being—influence students' abilities to adopt particular STEM identities are yet to be explored. The literature about how students describe the nature of being a particular STEM discipline is fragmented among each discipline. Few studies examine how ontologies across STEM disciplines influence students' identities and perceived access to particular career pathways. This work is a first step in exploring these connections for a broad range of STEM topics. This research study aims to explore students' ontological perspectives of what it means to identify with the STEM field (i.e., science, mathematics, physics, and engineering); and how the connection between these perceptions creates supports/barriers for students, in general, to identify with STEM roles. We also explored how students discussed their ontologies of STEM roles for students highly interested in engineering careers. Understanding these patterns of access can begin to create more equitable ways in which students can begin to see themselves as the kind of people who can do, enjoy, and be recognized within STEM.

Conceptual Frameworks

STEM Identity

Our description of what it means to be a science, math, physics person and an engineer has been conceptualized from the work of Gee (2000). He defined identity as, "When any human being acts and interacts in a given context, others recognize that person as acting and interacting as a certain 'kind of person' or even as several different 'kinds' at once" (p. 99). In this definition, it is important to note that identity is contextualized, socially constructed, and self-reflexive. Additionally, the qualitative work of Carlone and Johnson (2007) capitalized on Gee's theory

of identity and created a model of three interrelated facets of science identity—performance, competence, and recognition. Being the kind of person who can do science, mathematics, and/or physics is not an isolated enactment; rather, it requires the recognition of others (i.e., teachers, parents, peers, etc.). For example, Turner, Steward, and Lapan (2004) conducted a study with over 300 middle school students and found that parents who supported their children's interest in science and mathematics positively predicted future mathematics and science career intentions. As well, "one cannot pull off being a particular kind of person (enacting a particular identity) unless one makes visible to (*performs for*) others one's *competence* in relevant practices, and, in response, others *recognize* one's performance as credible" (Carlone & Johnson, 2007, p. 1190, emphasis in original). These dimensions are not distributed equally among individuals; for example, Tonso's (2006) study found some students who were highly recognized as engineering students, were not necessarily students who demonstrated equally high levels of competence. The study also found that several women in an engineering program with high levels of competence and performance were seldom recognized as engineers (Tonso, 2006). The three dimensions—performance, competence, and recognition—in the context of STEM broadly have served as stepping stones towards elucidating what it means to hold a particular STEM identity.

Expanding Carlone and Johnson's (2007) three dimensions of science identity, Hazari and colleagues (2010) reframed the approach to understanding identity to include an additional aspect for students at the transition from high school to university, an interest in the subject. Interest was added as these students were not already committed to a particular career pathway as they were in Carlone and Johnson's (2007) study. The constructs of identity, interest, recognition, performance/competence (i.e., ability to achieve good grades and the ability to understand concepts) have been quantitatively measured for physics (Hazari et al., 2010). These self-reported beliefs capture students' internal thought processes—how a person sees themselves—for multiple subject-related identities. These self-beliefs have been used to understand practical outcomes like career pathways in STEM (Cass, Hazari, Cribbs, Sadler, & Sonnett, 2011; Cribbs et al., 2015; Godwin, 2014; Godwin, Potvin, Hazari, & Lock, 2013; Godwin et al., 2016; Hazari et al., 2010); however, how students perceive the nature of these identities, their ontological perspectives, is not well understood. The trajectory of how the multiple subject-related (STEM) identities have been theorized and modeled using qualitative and quantitative data is depicted in Figure 1.

Ontological Perspective of STEM Identities

Ontology, as described by Dall'Alba (2009), is "‘being-in-the-world,’ which emphasizes that we are always already embedded in, and entwined with, our world, not simply contained within it" (p. 35). That is, learning to become

Figure 1. Our trajectory of understanding students' STEM role identity. These sources have focused on science, mathematics, and engineering as subjects; technology has not been included in this development.

a “math person,” “physics person,” “science person,” or “engineer” involves what one knows, what one can do, and, as emphasized in this study, who one is and whom one is becoming. In this way, ontology, or what it means to be a person in a particular role, is a precursor to and important aspect of identity development, or how a person positions themselves and is positioned by others in that role. Blaikie (2000) describes ontology as “claims and assumptions that are made about the nature of social reality, claims about what exists, what it looks like, what units make it up and how these units interact with each other” (p. 8).

Educational research has begun to explore ontology and the influence on educational practices and research. Researchers have begun to acknowledge the implications of ontology for interpretive research, where interpretive research “describe[s] social inquiry that derives knowledge claims from the interpretation of lived experiences of individuals or groups” (Walther, Sochacka, & Kellam, 2013, p. 628). In some cases, educational practitioners recognize the impact ontology has on students' perceptions of what constitutes scientific knowledge (Roth & Lucas, 1997). Kittleson and Southerland (2004) identified the impact that ontology has on the construction of scientific knowledge in an engineering context. A student's misconception or ontological understanding of a concept can either contribute to their understanding of a new concept or serve as a barrier to assimilating new scientific knowledge. Capobianco et al. (2011) explored elementary school students' ontological beliefs of engineers and engineering. They discovered elementary students held limited conceptions of what constituted an engineer or what qualified as engineering. Even more troublesome was that more than half of the students when asked to draw a person drew male engineers. These studies begin to establish the foundation for exploring the

implications of ontology on learning, environments, and identity development.

When exploring the construct of identity as related to ontology, researchers have measured role identity salience amongst students, that is, the ways students describe a particular STEM role identity as the basis for understanding how that ideal role relates to how they see themselves in context (Varelas, 2012). This approach relies heavily on the ontology of the student. The ways that a person has defined or their personal reality of what constitutes a science, physics, math person, or engineer provide insight into their ability to internalize those roles and see themselves as those kinds of people.

In this work, we explore *how* students interpret the meaning of what it means to be a “math person,” “physics person,” “science person,” or “engineer” through the philosophical study of the nature of being—ontology (Creswell, 2013). We asked students about being a math, science, or physics person as these ways of describing these types of roles are consistent with students' own ways of talking about these roles and prior literature with K–12 students. Physics was intentionally separated from a science person because prior work demonstrates there is a “strong relationship between a physics identity and persistence in engineering” (Cass, Hazari, Sonnert, & Sadler, 2011, pp. 13–14). Engineering as an ontology is also framed differently from mathematics, science, or physics to be consistent with both how K–12 students talk about these roles as well as prior literature. Measures of engineering identity for K–12 students, unlike identity measures for mathematics and science, use the word “engineer” (Capobianco, French, & Diefes-Dux, 2012). This choice is consistent with other research in engineering education with K–12 students (Capobianco et al., 2011, 2012; Hegedus, Carlone, & Carter, 2014;

Yoon, Dyehouse, Lucietto, Diefes-Dux, & Capobianco, 2014). These authors have used an instrument titled the Engineering Identity Development Scale that asks elementary students direction about engineering and becoming an engineer (e.g., “When I grow up I want to be an engineer”) after explicit instruction in engineering. Similarly, we have asked students about what does it mean to be an engineer. Our research explores participants’ realities of what a STEM person is, in their own words. These words are their expression of their reality of what describes, defines, and/or embodies a STEM person. Congruence between these expressions and self could be critical to understanding engagement, and subsequent pursuit of a STEM career.

Research Questions

Using the elements addressed in the ontology and identity frameworks, we explore students’ responses to three interview questions in the areas of science, mathematics, physics, and engineering. 1) What does it mean to be a [math person, physics person, science person, and an engineer]? 2) Are you a [math person, physics person, and science person]? 3) Can anyone be a [math person, physics person, science person, and an engineer]? Through these questions, we explored students’ ontology of what it means to be the type of person in each of the four roles. We also probed students’ perceptions of themselves and whom they felt could become a science, math, and physics person and an engineer. How students described these particular ontologies and who could take on these identities provided an understanding of the accessibility of these identities for students. We used student responses to these questions to answer the research questions of our study:

RQ1: How do students describe what it means to be a math person, physics person, science person, and an engineer?

RQ2: How do students’ STEM ontologies impact their perceived access to STEM careers for themselves (i.e., self-ascribed identities) and students in general?

RQ3: How are students’ engineering career interests informed by their STEM-related role identities?

Methods

The data for this study came from 17 student interviews at two different high schools, one in the Midwest and one in the Mountain Region, as a part of the Sustainability and Gender in Engineering (SaGE) project (NSF grant number 1036617). The focus of the larger study was to investigate how sustainability topics in high school science classrooms might provide connections between engineering as a potential career option and making a positive impact in the world, especially for female students. As a part of the larger study, a nationally representative paper-and-pencil survey

measuring students’ career intentions, sustainability attitudes, mathematics and physics identities, demographic information, and the name of their high school and high school science teachers was collected from 6,772 students at fifty 2- and 4-year institutions across the US. The students in the sample were enrolled in required general education English courses to gain a representative sample of both STEM and non-STEM students. These students retrospectively reported their experiences in their last chemistry, biology, and physics courses in high school.

From these data, the research team built a regression model of how students’ experiences in their high school courses predicted the choice of engineering in college. Four specific pedagogies in physics courses were found to be the strongest predictor of women’s engineering career choice: teaching concepts before formulas, learning topics relevant to students’ lives, discussing disease-related topics, and learning life-cycle analysis. We filtered the data by students who reported all four of these pedagogies had occurred in their high school classes. Then, we contacted the teachers at each of these high schools to see if they would allow our research team to come on-site and collect data for a week during the spring semester of 2013 while they were teaching some aspects of the pedagogies found to predict engineering choice in college. The teaching strategies and their effects were the focus of a different study and are outside the scope of this paper.

After initial teacher recruitment, we obtained a site letter from the principal at each school which we filed with the Institutional Review Board. Teachers were sent consent forms via email. Packets of student assent and parent consent forms were mailed to each teacher. The signed forms were collected from the teachers upon the site visit team’s arrival. Students who did not return both forms were not included in the data collected on site. Students who did return assent and consent forms were given a shortened version of the SaGE survey and observed in class. The short version of the SaGE surveys included students’ interest in different STEM careers, prior performance in mathematics and science, and their demographic information and allowed us to select students for interviews about their perceptions of STEM. Our work in this paper focuses on these student interviews.

Participants

The 17 students in this study ranged from freshman to seniors across Integrated Chemistry and Physics, Physics, Chemistry, AP Chemistry, and IB Physics classes at two high schools. The selection criteria for student interviews included an interest in engineering (especially for women); high or low physics and/or mathematics identity; and/or changes in attitudes toward science between middle school and high school along with observable engaged classroom participation and students indicated as interesting cases on the above criteria by their teachers. Information about

Table 1
Information about students selected for interviews.

High School Teacher	Course Taught	Pseudonyms	Gender	Race/Ethnicity	Engineering Career Interest
Midwest – Mr. A	Integrated Chemistry & Physics AP Physics	Brian	Male	White	High
		Dan	Male	White	Mid–low
		Crystal	Female	White	Low
Midwest – Mr. B	Chemistry AP Chemistry Integrated Chemistry & Physics	Kate	Female	White	Low
		Ashley	Female	White	Mid
		Ben	Male	White	High
		Amanda	Female	White	Mid
		Sara	Female	White	High
Mountain Region – Mr. C	Chemistry AP Chemistry Physics IB Physics	Henry	Male	Latino	Mid–high
		Adlai	Male	Latino	High
		Lidia	Female	White/Native American	Mid
		Allen	Male	White	High
		Schuyler	Male	Latino	High
		Ana	Female	Latina	High
		Samantha	Female	White	High
		Mary	Female	Latina	Low

participants is included in Table 1. All students in the study except one had prior or current formal instruction in physics.

The participants were asked to complete an interview with the research team during the school day, before school, or after school. Student interviews were typically 30 minutes in duration. We asked students about their perceptions of their class and teacher, attitudes about STEM, beliefs about what it means to be a math person, science person, physics person, or engineer, career interests, the support they receive for their career interests (including family support), and perceptions about school culture.

In our interviews, when we asked students “What does it mean to be an engineer?” most of the students in the study responded with a long pause or had difficulty answering this question. Only students with family members who were in engineering-related professions or who had a high engineering interest (five out of seventeen students) could easily answer this question. This outcome is not surprising as we know that “teaching engineering education in elementary and secondary schools is still very much a work in progress” in the United States (National Academy of Engineering and National Research Council, 2009, p. 2); consequently, high school students have little to no exposure to engineering-related concepts and, thus, have a more difficult time constructing an ontology of what it means to be an engineer. For students who were unable to answer the originally posed question, we reframed this question to “What do engineers do?” This change of wording does shift the types of answers that students gave; however, describing the actions or activities of a role like being an engineer still can shed light on how students perceive what it means to be or embody that role. This change also allowed us to access students’ description of an engineering role for students with less engineering interest or exposure,

which provided key contrasts in students’ perceptions of what it meant to be and who could be an engineer.

Analysis

The data from the student interviews were audio recorded and transcribed verbatim. These transcripts were analyzed using NVivo 11 (QSR International, 2015). We analyzed the data through a modified constant comparative approach that used a coding–recoding cycle to inductively identify major themes and connections between the questions asked and deductively code for the three constructs of identity used in the framing of this research (Miles & Huberman, 1994). This method allowed us to approach the data in a systematic way. We iteratively coded the transcripts to examine a single interview, then multiple interviews, and, finally, across interviews to ensure complete coder agreement among the research team.

First, we used open, inductive coding to examine phrases of meaning within students’ own words and allow themes to emerge without predetermined coding categories (Strauss & Corbin, 1990). In this work, we deductively coded for instances of the identity framework including constructs of interest, performance/competence, and recognition beliefs to understand how students described what it means to hold an identity in each of the STEM areas after the inductive coding. The goal of this approach was to answer the research questions guided by our theoretical frameworks without biasing the emergent results of the analysis. Finally, axial coding was conducted to look for connections between the inductive and deductive codes within an interview as well as across interviews in each of the STEM context areas we asked students about.

Once we identified overarching themes, we created a visualization of how students saw themselves and how they

Figure 2. Diagram of students' perceptions of STEM subjects and the frequency of agreeance.

typified each of the four roles (i.e., science, mathematics, physics, and engineering), which is shown in Figure 2. This diagram allowed us to draw connections between students' ontologies of what it means to be in these roles as well as how they viewed the accessibility of the roles. This process was interpretative and relied on the researchers' understanding of STEM and the environment of the high school classrooms. We acknowledge that we inferred meaning from how students described their own identities and the identities of an "ideal" STEM person to their perceptions of reality and what it means to be a STEM person.

Overview of Findings

This section highlights the overarching themes of how students described what it means to be and who could be a science, math, physics person, and an engineer. In answering Research Question 1, we present an overview of how students described being a science, math, and physics person. In conjunction with Research Question 1, we present findings on the differences between these subject-related role identities and draw connections between students' ontological perceptions of what it means to be a particular kind of math, science, or physics person with engineering. We answer Research Question 2 by highlighting students' perceptions of access, that is, how they describe who can be a science, math, physics person, and an engineer. Lastly, we provide individual narratives of how students with strong engineering career interest described how their STEM ontologies informed their engineering career interest to answer Research Question 3.

Since the student narratives consist of connected characteristics and attributes for each subject, in relation to one another, we found it appropriate to talk about each STEM

subject in conjunction rather than as separate entities. This interconnected nature of students' interviews is further highlighted in the visualization we created in Figure 2. This figure outlines similarities and differences between students' ontologies of a math, science, physics person and an engineer. For each of the characteristics, in Figure 2, we incorporate how many students agreed with the statements. The commonalities and differences among each STEM-related subject are discussed in more detail in the sections that follow. We argue that by examining students' ways of being and understanding of STEM identities together, we can better understand how they assume a subject-related role identity.

Similarities Between Mathematics, Science, and Physics Ontologies

In discussing what it meant to be a math, science, and physics person, students described three persistent beliefs that one must easily understand concepts taught in class (we mapped this theme to performance/competence from the identity framework), that one must be inherently interested in the subject and get enjoyment from learning more about it (we mapped this theme to interest from the identity framework), and that mathematics is integrated into science. This integration of mathematics into science was unidirectional. Students discussed mathematics playing a key role in science, but that science was not integrated into mathematics.

Students repeatedly discussed that a math person or science person needs to just be "smart" and have the subject material come naturally. This result highlights an important and concerning finding of how students perceive mathematics and science ontologies. These beliefs may be particularly exclusionary for students who may not describe themselves in these terms. Amanda stated,

...a science person just, they understand it very well and like it just comes naturally to them. That's how I think of a science person or like a math person, like it, just comes naturally to them and they can understand concepts just maybe like reading through it like once or twice.

While Amanda's ontologies of a math or science person were focused on having a natural ability, she also held the belief that natural ability was not enough. She felt that a science person must put some effort into understanding the content. Mary also supported this connection. She also described the importance of effort in understanding science-related topics as a part of being a science person, "you've just got to put time into it and effort and if you are interested in it, you might as well." Ana, in particular, discussed her mathematics and science ontologies as both static (i.e., comes naturally) as well as dynamic or able to be developed by putting in effort. These discussions of both having an ability to understand and do well in the subject that can, within limits, cultivate what it means to be a math or science person shed light on how students' construction of STEM ontologies can support (or not) future identity development. Students associated mathematics as a support subject that advanced their understanding of science and physics.

Students discussed communication or transmitting knowledge about the subject to a peer as part of what it means to be a math or science person. Easily communicating knowledge was also associated with students' perceptions of being a math and science person, as stated by Schuyler. He stated that one is a math or science person if they "talk about it," are "able to explain it to others," and are "able to do it by written explanation." These descriptions, which were consistent with other students, emphasize students' beliefs that to be a particular kind of STEM person, one must be able to perform the actions associated with the role, including appropriate science discourse. Research has found that writing in mathematics supports reasoning and problem solving: it "deepen[s] student learning and [is] a tool for helping students gain new perspectives" (Urquhart, 2009, p. 3). When students discussed what it meant to be a math and science person, their responses varied in nature from someone who simply understands the subject to someone who not only understands the subject material but can also communicate it to others. Nine students described a math or science person as someone who could move beyond rote memorization and acquire the skills to translate complex concepts into understandable ones.

When discussing similarities among different STEM ontologies, students focused on the particular types of knowledge that were important to science and physics. Common phrases emerged for describing both ontologies such as knowledge of "how things work," "why things happen," and "knowing lots of facts." Students often drew parallels between being a science person and a physics

person, as described by Schuyler, "I think it's like most of the stuff I said about the science person." Students described these two ontologies similarly; however, the connection between a science and physics person was discussed, not surprisingly, in terms of physics being a subcategory of science. As described later, students believed that being a physics person had additional requirements for deep knowledge of physics content and ability to just get it beyond how they discussed a general science ontology.

Students also described interest as a central component to mathematics, science, or physics ontologies. The theme of interest is best highlighted by Schuyler who said, "to be a science person you just kind of have to have that interest or that spark that when you see something you kind of say, 'I wonder why that works or I wonder how that works or I wonder why that happens.'" In mathematics, Ana described the importance of interest in what it means to be a math person stating, "even if you're not good at it...you're actually interested in it." Students regularly agreed that interest in the subject was a key part of what it meant to be that type of person. Few students drew connections across subjects in their discussion of interest, but they all felt it was important to each individual ontology.

Difference Between Mathematics, Science, and Physics Ontologies

Differences between students' ontologies of a math, science, and physics person also emerged as highlighted in Figure 2. Students described science people being immersed in science through hands-on activities like experiments and research. They also characterized science people as having open, interest, flexible, and willing minds for exploration of science topics. As noted by Dan, "You have to be open and can't really have a closed mind or anything. [You] have to have an understanding how things work and then be willing to change what you think about something." Dan felt that being a science person can be learned through exploration and one's willingness to be open-minded. In contrast, an open or exploratory mindset was not discussed as a part of what constitutes a math or physics person. Students described their performance in mathematics as a determining factor towards seeing themselves as a math person. Specifically, twelve students addressed the need to be "pretty good at working with numbers, processing things," "be able to figure out...solve," "doing math in general," and "using math." Mathematics was also linked to applying basic mathematical principles as stated by Brian, "[Math is] learn[ing] how to take fundamentals and apply them to harder topics."

Students' conceptions of physics people were the least well-defined beyond performance/competence and interest. This outcome might be due to many of them having limited exposure to physics content; however, all the students in this study had taken at least an Integrated Physics and Chemistry course if not a full course in physics, which

taught general concepts of physics and modeling motion. High school is the starting point for students to clearly differentiate between physics and other science courses (Hazari et al., 2010), making it a challenge to break down students' spontaneous theories about physics (Glynn, Britton, & Yeany, 1991) and thus creating ill-defined conceptions about the field. Students also made distinctions between what it meant to be a physics or science person. For example, Schuyler noted,

With physics it's more towards the side of like movement of things...movement of a, objects, or of light, sound, just more towards having an interest in why things move or interact with each other instead of like why does a flower grow or why, why does soap kill bacteria?

Schuyler's understanding of a physics person was associated with an isolated subject, mechanics, as opposed to a science person, which was associated with the practical connections to everyday life. He was not the only student to describe physics in limited terms or to focus on the belief that being a physics person meant one understood abstract concepts. Two other students also stated a similar opinion. These students did not connect physics in the same ways as they did science in having a practical effect on or providing a deeper understanding of the world around them.

Additionally, most students discussed natural ability for mathematics, science, and physics ontologies. This discussion was more nuanced for students in describing physics. Students more often discussed a need to put in effort and work hard to understand concepts rather than expecting and understanding of the subject "just come naturally." This difference may be due in part to students' entering their physics courses with misconceptions about physics theories. A research team found that students brought to the classroom theories of motion more in line with Aristotelian perspective as opposed to the Newtonian perspective taught in class (Glynn et al., 1991). These researchers posited that,

when the tenets of the scientific theories conflict with spontaneous theories [a child's reflections of everyday experiences] or describe a world that does not fit with the students personal experience, they are rejected outright or accepted as theories that apply only in the context of formal science and are useful only to the extent that they are interesting or are necessary to achieve a good grade in the course. (Glynn et al., 1991, p. 29)

Therefore, it may be difficult for students to develop a perception of having a natural ability in physics because of the misconceptions they first need to overcome coupled with the late exposure to physics content, at the start of high school.

The results of this investigation provide a context in which we can begin to understand how students better

develop ontologies of what it means to be math, science, and physics people to inform how they conceptualize what it means to be an engineer. Students focused on some similarities among these different subjects especially in how interest and abilities to understand and communicate subject material were important in being these kinds of roles. They also connected mathematics as essential to both science and physics. However, differences in how students conceptualized these roles were also seen in student interviews. Students most often associated mathematics with a natural ability and performance in a formal educational setting. The role of a science person was more often described as investigative, requiring not only an understanding of the subject area but also the ability to ask questions and be open-minded. Physics was the least well-defined role for most students and focused mainly on how difficult the subject was in relation to students' performance as well as abstract concepts not connected to everyday life, unlike both mathematics and science.

Students' Engineering Ontologies

How students defined what it meant to be an engineer was distinctly different from the other role identities focused on in this paper. Rather than focusing on being knowledgeable about content or simply being interested in the subject, students focused on the practical applications of engineering: making things, making life easier for others, designing, and being efficient. This result may be, in part, due to the wording of the follow up prompt that focused on what engineers did, but even students with more well-formed conceptions of engineering (i.e., Adlai, Schuyler, Sara, and Brian) focused on the practical and hands-on focus of engineering as different from mathematics, science, or physics. For example, Adlai talked about an engineer as different from a science person saying, "Well, the thought processes, you have to think of like the simplest way to do something whereas in other areas of science you might just want to like get all the details and just explore everything, all the possibilities." Some students made an association between being a "mathematically and scientifically minded" person as someone who can do engineering. Adlai said, "...if you're like mathematically minded, or even science-minded like as long as you're interested in that field of engineering I think you could be an engineer." Allen agreed saying, "you have to be a science person and a physics person and a math person to be an engineer because it kind of includes all three...like you wouldn't just be learning individual subjects, you'd have to be learning all of them."

Physics was commonly linked to engineering; when asked to describe engineering, students stated, "using physics to build something" (Samantha), "know the mechanics of stuff...that's what I would see as a physics person" (Ana), and "I feel like engineers can be good physics people" (Ana). The majority of students connected the idea of what it meant to be a physics person to engineering in

terms of the knowledge base and the application of the subject to one another than to either science or mathematics. This connection is concerning as physics was the subject with the fewest students having a clear idea of what it means to be a physics person.

Whereas students used phrases such as being “smart” or “good at” to describe what it means to be a math, science, or physics person, such phrases were not brought up when students were asked to describe who can do engineering. However, students had unique descriptions of what engineers do. For example, they included themes of coming up with ideas, “making everybody’s life easier” (Adlai), “seeing things differently” (Allen), “build things and create stuff” (Ashley), “new ways of building stuff” (Ben) and testing things. When analyzing student narratives, engineering was highly associated with someone who is creative or a creative thinker. We do acknowledge that many students do not have direct experiences with engineering in high school. Yet, many of the students we interviewed were interested in engineering careers, and the school in the Midwest had a Project Lead The Way program. Students who participated in engineering-related projects, in their science and physics classes or in activities such as Project Lead The Way, may have better perceptions of what it means to be an engineer and what an engineer does in the context of our study.

Influence of Ontologies on Students’ Perceived Access to Particular STEM Roles for Themselves and Others

Students’ ontologies and their self-ascribed identities. We not only asked students what it meant to be a math person, physics person, and an engineer, we also asked them to describe if they were a math, science, or physics person and who could be a math, science, physics person or engineer. The first question focused on how they conceptualized themselves in relation to their described ontology—their self-ascribed identity. We have conceptualized identity as the authoring of oneself in a STEM context, using the sub-constructs of interest, performance/competence, and being recognized as someone who can do a particular STEM-related subject. We examined the alignment of students’ described ontologies and identification as a particular STEM person. Overall, most students considered themselves math people (7 participants) and science people (11 participants) over physics people (4 participants). We did not ask students if they saw themselves as engineers because literature shows that this identification does not occur during high school (Godwin, 2014; Godwin & Potvin, 2015; Godwin et al., 2016). This section highlights how students’ interest, performance/competence, and recognition in STEM subjects (mathematics, science, and physics) supported or hindered their STEM-related role identities and connections that they made between the ontologies discussed previously and their self-ascribed identities in these STEM subjects.

Students described their identification with a subject based on their performance/competence beliefs and interest

in the topic. These ways of seeing themselves as a math or science person were usually consistent with how they described what it meant to be a particular role in general. For example, Amanda shared that she thought mathematics and science were “kind of integrated.” She strongly identified as a math person, but stated, “I can, you know, stay afloat in science.” She did not identify as a science person because “it’s not like it’s hard for me, but it’s not that interesting.” Even though she considered mathematics and science as related to one another, a lack of interest prevented her from seeing herself as a science person. Another student, Samantha, saw herself as a science person based on her performance on standardized tests as well as an understanding of concepts and general interest stating, “I do like science and the experiments and everything.” Samantha often engaged in science conversations outside of the classroom, stating “I have a lot of conversations about things that we’ve learned that day or things that we don’t understand outside of [Mr. C’s] classroom and at lunch or texting.” However, she also stated, “I would consider me a science person, but umm, I don’t know if other people would.” We believe the lack of recognition may have limited her identity formation since she did not believe that others saw her as a science person.

Students’ performance/competence beliefs often served as a barrier to identifying as a STEM person. When probed why she did not identify as a science person, Lucy stated, “sometimes I don’t get it but, um, I mean like I do help the world, but I don’t get like some of the stuff that goes in science.” Lucy’s ontology of a science person was someone who understands how the “world gets affected” and “caring for the world” through science. However, her identification as a science person was not only contingent on her interest in “helping the world” but also her performance/competence beliefs, which she described as lower than her peers’. Alternatively, when Mary was asked about being a math person she stated, “I get good grades in it [math],” her ontology of a math person was “being smart, good with numbers,” “put[ting] time into it,” and being “interested in it.” However, when asked if she saw herself as a math person, Mary stated, “No, I don’t like math.” Although she performed well in her mathematics courses, her lack of interest in the subject deterred her mathematics identity formation. These findings are consistent with prior quantitative work that indicates that performance/competence beliefs are necessary but not sufficient to form an identity. Both interest and recognition are needed as well (Godwin et al., 2016).

Students who considered themselves as physics people often highlighted their performance/competence beliefs. For example, Crystal stated physics people are “people that are good at physics” and then continued to state how she saw herself as a physics person, “I think I’m good at physics. I have an ‘A’ in the class... I could tell you like what gravity is or stuff like that, like the big concepts. I feel like I’d be comfortable with those.” Crystal was confident in

Figure 3. Students' perceptions of who can assume these STEM-related role identities.

her abilities as a physics person mostly due to her performance in the subject. Crystal also attempted to demonstrate her interest in physics outside of the classroom by talking about it with her peers. However, since her peers did not take physics (and were not interested in it), it was difficult for her to perform her role as a physics person with her friends. Crystal stated, "at my lunch table they find it kind of annoying because I bring [physics] up all the time...they just kind of roll their eyes." Perhaps it was difficult for Crystal to demonstrate her interest in physics as she was in social settings where talking about physics was not a popular conversation. Nevertheless, she affirmed her interest in physics to her peers by stating to her peers, "if you would have taken physics, it's like it's a lot of fun."

Schuyler also saw himself as a physics person stating, "it really does interest me I really do enjoy it and I try to link it with stuff outside the class." His ontology of a physics person differed from Crystal's. He included more instances of interest-related topics as the central part of who can be a physics person, "you have to have an interest." Schuyler also saw the world through the eyes of a physics person as noted in his following account:

I do find myself in an every day, um, thing like asking myself questions, well, why does that work? And then I'm like oh, well, we learned about this. And, um, in class, like I was just, I was driving home last night when it first started to snow, and my driveway's kind of steep and I pulled up and tried to park and I just kept sliding down, and I said well, why can't I park? And I'm like well, because the snow's there and the snow's slick and it reduces the friction so gravity pulls me down and that just kind of flashed through my head...

Schuyler's ontology of a physics person was similar to that of a science person. Interest in understanding how the world works and its application was the undergirding aspect of both of these disciplines. His interest in both science and physics facilitated a strong identity in both subjects.

Students' ontologies of STEM people provided a metric of the type of people who were "good at" or engaged in STEM. They used these descriptions to measure their self-perceptions to determine if they could see themselves as a STEM person. If there were incongruities between their ontologies and themselves, they were not likely to describe themselves as having a STEM identity; likewise, if their ontology aligned with their perceptions of themselves, they often claimed a STEM identity. Factors that contributed to their ontology were not explored in this study. In this study, we found that students' ontologies either served as barriers to STEM identification or provided access to a STEM identity.

Students' ontologies and described perceived access. Students described access to science, mathematics, physics, and engineering identities along a continuum from possessing natural ability to developing extensive knowledge and skills in their answers to the question, "Can anyone be a math, physics, science person, and an engineer?" We provide a representation in Figure 3 of how students described access to the four subjects on a scale from natural ability to extensive knowledge and skills to be a particular type of STEM person in relation to their perceptions of who can assume these STEM-related role identities. Based on students' discussions about the different STEM subjects, mathematics and science were linked to more inherent abilities held by most people, whereas physics and engineering required more comprehensive STEM knowledge held by elite or "super smart" people. A gap between natural ability and extensive knowledge separated students' perceptions of being a math and science person from physics and engineering. Students discussed anyone being able to be a math or science person if he or she were interested and worked hard enough, but physics and engineering were less accessible from students' descriptions of who can assume these subject-related role identities. While all students, except for one, had taken or were currently taking physics, they still saw it as less accessible than science and math. At the time of the interview, few students were involved in engineering-related activities; however, even those students

that were exposed to engineering still found it difficult for anyone to assume the role identity of an engineer.

Overall, students were most accepting of anyone being able to be a math person if they were sufficiently interested, put enough effort into understanding the concepts of mathematics, and had a positive attitude. As Schuyler described, “You just have to have a good attitude towards it [math].” Only two students, Ben and Adlai, described that it might be difficult for others to be a math person, but both acknowledged that with enough effort, anyone could assume these roles. Ben stated, “I don’t think anybody could...you kind of have to try harder if you’re not in that mentality.” All other students highlighted effort as a contributing factor to seeing others as math people.

Science access was similar in description including interest and effort as requirements for who can be a science person. However, students also described how some people “see or understand things [science] better,” and how science has a more hands-on and less algorithmic approach in understanding the subject than mathematics. Many students compared who could be a science person with being a math person. Most agreed that mathematics was more “straight-forward,” and foundational to understanding and learning science, except for Ben who believed it was “harder to be a science person than a math person.”

When describing who could be a physics person, students put more limitations on the type of person that could assume this identity. Lucy stated, “I think some of the smarter people...some of the people that know their formulas and stuff and that can memorize them really good, and I think they could be physics people.” Many students felt similarly and described that being a physics person involved being smart and was different from being a math or science person. Being interested and “able to grasp the knowledge” (competence) were also essential in students’ descriptions of being a physics person similar to mathematics and science, but they also included additional qualifiers like being sufficiently motivated, being a “smart person,” having perseverance, and being a “certain kind of person” (different from the “average” student). They explained that being a physics person was different or more challenging when compared to other science topics. Perhaps students feel physics is more challenging than other science because their exposure to physics begins later in high school and as an optional class rather than as a required part of students’ trajectory. Another reason why students, particularly female students, perceive physics is challenging or for certain type of people may be due to a filtering process. In one of our participating high schools, there was a consistent low enrollment of girls in physics class. Crystal alluded to the fact that physics courses are not highly emphasized. She said,

I feel like it [physics] should be pushed more. Like they pushed, ah, Earth and Space really hard and they’re like you need to take that, you need to take that...But I feel

like it [physics] should be more pushed because it is a good class. I really enjoyed it and I think I’ve learned a lot...Maybe that’s just what I like because some girls haven’t heard of it...

When describing who could be an engineer, students saw the subject as least accessible. They repeatedly described those students as people who saw the world or problems “differently” than most. This role identity involved “a lot of thinking,” and extensive knowledge of “how everything works in the world,” or “knowing *it all* to apply all subjects” (Allen; emphasis ours). Many students described being a math, science, and especially physics person as essential to being an engineer.

Most students stated that an engineering career was not “for them.” While all students that were selected for this study indicated that they were open to an engineering career marking moderate to significant interest on our shortened survey for participant selection, interview data revealed that most students had other career interests (e.g., accounting, interior design, medicine, equestrian management, marine biology). In the next section, we describe the four students in our sample that were interested in an engineering career and how they described their ontologies of what it means to be an engineer and the connections to their identities and career pathways.

Individuals Interested in Engineering Careers

A report profiling over one million graduated high school students’ interest in STEM careers found that of the students interested in STEM-related fields, “57% will lose interest in STEM by the time they graduate from high school” (Munce & Fraser, 2012, p. 4). We present four cases—Brian, Sara, Adlai, and Schuyler—who identified as the kind of people who are interested in science, mathematics, and physics, which led them towards an interest in an engineering career path. The four students that demonstrated high interest in engineering and could further articulate their career interests in interviews came from all three participating high schools. While two other female students indicated they were highly interested in an engineering career on the survey (i.e., Ana and Samantha), interview data revealed that only Sara had a clear interest in pursuing an engineering career. Additionally, Ashley, a student who indicated being moderately interested in a career in engineering stated, “it kind of depends on like I guess the next two years of high school and what kind of classes I take and stuff,” for her to determine if she would pursue an engineering career. At the time of the interview, Ashley did not have exposure to physics, which has been found to be a gateway towards interest in engineering. Two other students, Allen and Ben, also indicated high interest in engineering on the initial survey. In their interviews, they discussed engineering as a possible option but were not yet committed to a particular engineering pathway.

For this paper, we chose to focus on the four students who had clear intentions to pursue careers in engineering, Brian, Sara, Adlai, and Schuyler.

Brian was in the Integrated Chemistry and Physics class with Mr. A when the interview was conducted. When asked if Brian thought of himself as a science person he stated, “I’d say about 95% science...” Evidence of his interest in science further unfolded in how he talked about seeing science relevant to life: “I mean, it’s everywhere. Science is coming to school, going home, science is everywhere. It’s just so fascinating to me how even this table has science. Everything has science. It’s just incredible.” Brian acknowledged that his interest in engineering stemmed from his three years of experience with Project Lead The Way, in middle school and high school, “but I learned most of what I wanted to do in there [engineering] in Project Lead The Way.” Brian developed a strong interest in an engineering career through Project Lead The Way, his interest in mathematics and science, and his desire to “make some good money and have a nice life.” In addition to his experiences in Project Lead The Way, Brian was in a vocational auto shop class, where he applied some of his mathematics and integrated chemistry and physics (ICP) skills, “once in a while we use math to like when you measure a brick road or something like that you have to get a micrometer out and I’ve used those skills in ICP.” Interest in physics has been commonly linked to career interest in engineering; however, in Brian’s case, his ontology of engineering was more connected to mathematics and science indicating that science course yield potential towards identifying as someone who could do engineering. Brian was deciding between mechanical and civil engineering; when asked about how he would choose between the two, he replied, I will “pick the one that fits me best, with math and science.” In other words, he was interested in the career that bests fit his identity as a math and science person.

Sara was one of our participants that identified as a chemistry person, stating, “it comes really natural...so, I kind of want to do something in chemistry.” With the support of her AP chemistry teacher, Sara identified that she was interested in a career in chemical engineering saying, “he [AP chemistry teacher] has definitely been a big like impact in where I wanted to go. I guess like for narrowing my, what I wanted to do, [AP chemistry teacher] was definitely like the biggest factor in it.” From prior work in an in-depth longitudinal study, Sara’s AP Chemistry teacher recognized her interest and outstanding performance and steered her towards a financially stable career (Godwin & Potvin, 2017). Sara’s identification with engineering was notable in her explanation of who could do engineering, “I think you kind of have to see things differently than most because I mean, I know I definitely look at the world a little differently and just can figure out, like I definitely look at things differently than most of my classmates...” To some extent, Sara believed that everyone was a math and science person:

math and science are two things that are in the world...you have to have math; you have to have science. If you’re going to figure out things you’re going to calculate them...And so, I think that everyone does, it’s just whether or not like you actually go and use it more...

Because mathematics and science are foundational subjects, which students learn throughout their primary and secondary education, Sara may have been equating this exposure to being a kind of person who does mathematics and science. The idea of some people “using it more” than others is associated with their different levels of interest. Sara went into an engineering career in college but later left engineering because of the learning environment experiences in college. Her college STEM experiences eroded her interest in an engineering career (Godwin & Potvin, 2017).

Adlai was one of the students who identified as a kind of person who was “mathematically and scientifically minded.” His discussions of physics and mathematics identities centered on performance, particularly around understanding concepts and knowing facts. His decision to pursue an electrical engineering career was fostered through his brother, who was an electrician. The physics and AP Chemistry courses he was taking helped further his interest in the field:

...it helps to have background on it like in physics class and chemistry, we did kind of electrical things so I got excited when I found out we were going to learn about that stuff because it would give me like more background on that and I could use that for my career.

Adlai was taking both physics and AP Chemistry courses as well as acting as a teaching assistant in general chemistry when the interview was conducted and strongly identified as a chemistry person rather than a physics person. This was evident in his reply to our interview question: “Would you say you’re a physics person?” Adlai replied, “not as much as a chemist—chemistry person...I feel like I understand chemistry a lot easier than physics sometimes, but um, I feel like physics isn’t too far out of reach either...” When asked if he saw himself as a science person, again he reiterated his interest in chemistry, “No, not in all areas, just certain areas like chemistry.” While quantitative research has found physics and mathematics identities are critical generally for choosing an engineering career (Godwin et al., 2016), these generalized connections may not apply for all students, especially those like Adlai. Although he discussed certain physics topics that were of interest to him (i.e., electricity and magnetism) due to their connection to electrical engineering, he did not identify as a physics person as much as he did as a chemistry person, “chemistry would probably be one of my stronger areas.” However, Adlai acknowledged the value of taking a physics course for people who were not necessarily interested in the subject:

It might not be something that relates necessarily to what you're doing exactly, but it definitely helps the, like practice problems solving skills, that's something that I definitely want to get better at so that's why I think it's definitely important for people to take that [physics]...it helps hone the critical thinking skills that you might apply to, not necessarily physics but in life of any other kind of job...

We believe Adlai's interest in engineering was more closely tied to his brother's occupation rather than the exposure to an engineering career in school. Other work has documented the importance of having a sibling or other relative that is an engineer or related STEM field in fostering students' engineering decisions (Godwin, Potvin, & Hazari, 2014; Yun, Cardella, Purzer, Hsu, & Chae, 2010). Overall, Adlai was recognized as a strong STEM student in his high school classes and was involved with science both in and out of the school environment. Adlai hoped to earn an electrical engineering degree with a minor in business because his aspiration was to start a business with his brother who holds an electrician license. In a follow-up study, Adlai was pursuing an electrical engineering degree at a large, public engineering-focused institution (Scott, 2014).

Schuyler identified as a science person, someone who "enjoyed physics a lot," having a natural inclination towards "building things, figuring out how things work" and "being able to apply it [physics] to real life..." When asked if he saw himself as a physics person, Schuyler used interest-related terms to describe his physics identity. When asked about mathematics identity, he alluded more towards performance-oriented perceptions. Schuyler had researched careers related to physics like mechanical and aerospace engineering, in addition to psychiatry because he found "it interesting how people's brains work, why they behave the way they do," and "human behavior is kind of interesting." This dual interest was due, in part, to the profession of his mother as a counselor and his uncle as an engineer at an international aviation company. His physics teacher also explicitly recognized him as someone who could do engineering. When Schuyler pitched the two career perspectives his physics instructor replied,

He's kind of said yeah, that would be a good fit [engineering], that would be a good career to go, you seem like you know, you seem like you have a good understanding of stuff. So I guess you could say when I talked to him [Mr. C] about it once or twice that he kind of wanted to push more towards engineering.

When asked if he would find his physics and science courses useful in a career like psychiatry, Schuyler replied,

I feel like it would be useful because I feel like everything interconnects even if it's not, even if it's not,

like a physics problem, having a background in physics and bringing something up science-oriented, um, maybe about the body or the brain or how something works, I can compare that to how something works in what I've learned in physics.

Similarly, he highlighted connections with liberal arts and social science to STEM subjects, as noted:

There's a lot of science in the arts. I feel like if you can connect to the two they're really one and the same because there is a lot of different things that we were learning about sound and how sound is created that we've kind of learned in choir and it's like oh, hey, that's kind of like when we do this in choir, um, I feel like they're interconnected not different.

Schuyler was continuing to explore his multiple interests across STEM and non-STEM subjects, and he saw himself as someone who could do a variety of careers including engineering and psychiatry. His curiosity about the world and the human mind has placed him in fields that may be considered polar opposites. Even though Schuyler researched engineering careers and had an interest in STEM-related subjects, we cannot infer his career choice based on our data. Since he had multiple, divergent interests and made connections across fields, there was a possibility he might have chosen a STEM career outside of engineering. A follow-up study conducted during his senior year of high school found that he was pursuing a career in fisheries biology (Scott, 2014).

This subsection has featured four cases of students interested in pursuing engineering careers. Each case highlighted different approaches to how each of these students became interested in engineering. While they are not holistic representations of all possible ways students might become interested in engineering careers, they offer unique insights on how students may enter engineering. For example, Brian's interest in engineering stemmed from his three years of experiences with Project Lead The Way, rather than the material from his Integrated Chemistry and Physics class. For Sara, the recognition and support of her AP Chemistry teacher led her to an engineering career trajectory. Adlai saw himself as a chemistry person rather than the other ontologies and identities that we probed and having a family member in an electrical engineering-related field influenced him towards that career. Finally, Schuyler's interest in physics and recognition as someone who could do engineering were not enough to steer him towards an engineering career due to his overlapping interest in how human behavior and the mind works. Overall, we cannot make declarative statements that all the students highlighted in this section chose to pursue engineering careers. In fact, many did not (Godwin & Potvin, 2017; Scott, 2014). What we do know is that they stood out as people

who could see themselves as engineers or students who connected their ontologies of what it meant to be these kinds of people with how they could see themselves, which is a first step in potentially choosing an engineering pathway and generally persisting in a STEM-related field, outside of engineering.

Discussion

We found both similar and different ways in which students described STEM ontologies in mathematics, science, and physics. Several students reported having an interest in a particular subject as a significant aspect of what it means to be a science or physics person. This connection to interest is consistent with prior research that has found interest to be a determining factor in identifying as a science or physics person (Potvin & Hazari, 2013). In contrast, students consistently highlighted performance/competence and effort as the most important factors for being a math person. This result is particularly interesting as it may highlight how students interpret mathematics ontologies differently in their secondary education from published literature on early post-secondary education. Prior quantitative findings with first-year university students showed that interest and recognition in mathematics “had significant and positive direct effect on math identity, math performance/competence had an indirect effect moderated through interest and recognition factors” (Potvin & Hazari, 2013, p. 3). Additionally, our finding is different from prior studies of how undergraduate women in engineering discuss what it means to have a mathematics or physics identity (Godwin & Potvin, 2015). Mathematics 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 mathematics was connected to everyday life. These differences may be due to students’ varying experiences with mathematics as well as the fact that we interviewed students with varying interest in future engineering careers. This finding also highlights the importance of understanding how students’ STEM ontologies are formed and change over time.

Some students described positive performance in science, but they lacked interest in the subject and thus did not identify as a science person. Our results indicate that the addition of interest may be particularly valuable in how students describe science ontologies and perceive that they can take on these roles in their own identities. The importance of interest is consistent with quantitative findings that state, “performance/competence beliefs are mediated by interest and recognition,” alone they may negatively predict mathematics and/or physics identity (Godwin et al., 2016, p. 326).

In prior research, recognition, in addition to interest, has been shown to be necessary for identity development in

mathematics and physics. Prior qualitative work (Carlone & Johnson, 2007; Godwin & Potvin, 2015) and quantitative work (Cribbs et al., 2015; Godwin et al., 2016; Hazari et al., 2010) have documented the importance of recognition on student identity development. Their findings have shown that “a satisfactory science identity hinges not only upon having competence and interest in science but also, critically, upon recognition by others as someone with talent and potential in science” (Carlone & Johnson, 2007, p. 1197). Recognition played an essential role for Sara, who demonstrated high levels of achievement in AP Chemistry and was thus recognized as someone who could be a chemical engineer. In our prior quantitative work, we found that being recognized as a physics and math person had the largest effect on identity development and engineering career choice (Godwin et al., 2016). However, in this study and our prior qualitative work in understanding engineering career pathways (Godwin & Potvin, 2015), we found that students’ narratives of how they saw themselves as physics and math people rarely included other actors or perceived recognition. We believe that lack of recognition experiences in students’ narratives do not indicate a lack of importance, but rather a self-focused narrative. Recognition may not be explicitly discussed because it is an external validation that is internalized in how students see themselves. Because this validation process is initiated by others, students may not cite it in their narratives about the types of people they see themselves as.

Our findings are consistent with previous work that found that students’ perceptions of a science role involved the practices of asking questions, thinking creatively, or memorizing facts and formulas (Shanahan & Nieswandt, 2011). Shanahan and Nieswandt’s work examined high school students’ attitudes about science in a Canadian context. Our work builds on their findings also to understand students’ descriptions of what it means to be a math, physics, and engineering person across two high schools in the US. We found that students were more likely to describe science or mathematics as role identities that anyone could assume if he or she were interested and worked hard to understand concepts. On the other hand, physics and engineering were perceived as more difficult, only for “smart” people, and require extensive knowledge of all STEM. These differences in students’ descriptions show a gap in who is likely to take on identities as a physics or engineering person over a math or science person.

Our findings may also begin to highlight one potential reason for the persistent lack of women in physics and engineering (National Science Foundation, 2017; Yoder, 2016). Other science and mathematics fields have achieved parity in the number of bachelor’s degrees awarded each year to women. Engineering and physics, despite significant research and outreach efforts, have remained stagnant—only awarding approximately 20% of bachelor’s degrees to women each year (National Science Foundation, 2017;

Yoder, 2016). The alignment of students' ontologies and self-perceptions may provide new ways to explore this importunate issue. If students perceive that physics and engineering are roles for the elite few rather than roles that can be taken on through deliberate practice, these beliefs may alienate particular students who do not identify as the top students in their STEM classes. Studies demonstrate that women often have lower beliefs about their abilities to perform well in STEM (Bandura, 1986; Ketelhut, 2007). If physics and engineering are perceived as subjects that require additional knowledge, skills, and expertise, beyond mathematics and science, these ontologies of what it means to be and who can become physics people or engineers may exclude women and other underrepresented students. The socially constructed ideas of exceptional "smartness" required to be the kind of person shown in our work and other work (Hegedus et al., 2014) may begin to uncover reasons for the persistent representation issues and provide leverage points for change.

Students discussed having natural abilities and requirements for "smartness" in their descriptions of STEM ontologies, especially physics and engineering. These requirements that students constructed for what it means to be and take on particular STEM roles may have significant negative consequences on students' intentions to pursue engineering pathways. Students described their STEM ontologies in fixed terms that someone had to be a particular way already rather than being able to develop important attributes or characteristics over time. The statically framed discussions of STEM ontologies are similar to research on mindsets. Yeager and Dweck (2012) highlighted how having a fixed and unchangeable mindset about aptitude "can lead students to interpret academic challenges as a sign that they may lack intelligence" (p. 302). From a fixed mindset perspective, the notion of ability is understood as innate and permanent (Dweck, 2006, 2010). We saw this fixed mindset reflected in students' accounts of who could be a physics person (i.e., "smart person" or a "certain kind of person") which may prevent students from seeing themselves as someone who can succeed in a STEM-related subject. Having a growth mindset allows students to understand that STEM-related subjects are not just topics that come naturally, instead, through appropriate learning opportunities over time can incrementally develop and create resilience rather than acceptance of intelligence as unchangeable.

These subject-related role identities are not fixed; educators may be able to support the development of STEM identities through a growth mindset established in the classroom setting (Yeager & Dweck, 2012). Dweck (2010) found that providing students with praise and encouragement fosters a growth mindset and a culture of risk-taking in the classroom, that is, "praising students for the process they have engaged in—the effort they applied, the strategies they used, the choices they made, the persistence they displayed, and so on" (p. 17). Many of the students who had a least defined subject-related role identity had fixed mindsets

of who can be a science, math, and physics person (e.g., being smart, having a natural ability, etc.). Shifting these students' ways of viewing STEM performance and competence to a growth mindset may open access to STEM subject for students who, currently, do not possess these "natural" abilities. Additionally, we believe helping students shift their mindset about what it means to be a science, math, and physics person may open doors for those who currently do not identify with these role identities. Most students agreed that performance/competence or the need to have the material come naturally was essential for becoming a STEM person; only one student, Amanda, spoke about requiring effort. The idea that mathematics and science must come "naturally" may deter students who need to put in effort to succeed in STEM-related subjects. A growth mindset may provide new pathways for students to see themselves as the kind of people who can engage in STEM and develop their ability to perform in or understand STEM-related subjects.

Limitations and Future Work

This research provides an understanding of how students describe particular subject-related role identities and how they perceive their peers and their own abilities to adopt these identities. We do acknowledge some limitations in our work that impact the claims we can make. First, our interview protocol did not explicitly ask students about their feelings of being recognized as a science, math, physics person or engineer. Consistent with previous qualitative work, students did not bring their perceptions of others into their narratives (Godwin & Potvin, 2015). Thus, we were unable to explore connections seen in prior quantitative findings related to recognition beliefs. We believe this limitation could be addressed with an interview protocol that probes if and how students are being recognized. Future work will explore how students describe what it means to feel recognized and the practical ways in which parents and teachers can provide this recognition in the classroom.

Additionally, rephrasing the question, "*What does it mean to be an engineer?*" to "*What do engineers do?*" may not be an ideal way of understanding students' engineering ontologies; however, it was a practical adaptation to the context and participants in our interviews. We acknowledge that the rephrasing of this question may have altered student responses to the interview probe and limits the comparisons that can be made to other STEM ontologies. One of the biggest challenges of studying students' conceptions of engineering in secondary education is that few have had direct or explicit exposure to engineering. This exposure is changing with an increased focus on integrating engineering into K–12 curricula (Honey, Pearson, & Schweingruber, 2014).

The participants in this study were selected based on four specific pedagogies in physics courses; perhaps having selected high schools with engineering programs

(e.g., EPICS) or curricula (e.g., Engineer Your World) students may be more informed about what it means to be an engineer. Further studies should target high schools with engineering-specific pedagogies or programs and explore how students' ontology of an engineer are shaped. Our work only explores a limited number of students' descriptions at one point in time. Due to this sampling, we cannot make accurate inferences as to whether students further developed these role identities or how their perceptions changed over time. Lastly, the generalizability of our results is limited to high schools with a focus on specific pedagogies in physics courses.

Conclusion

The results of this work begin to fill the gap in understanding how students perceive what it means to be the kind of people who engage not only in science but also mathematics, physics, and engineering and how those ontologies impact their identities as STEM people. Students saw mathematics, science, physics, and engineering as related but provided different descriptions of who could be the type of person who engaged in these subjects. We found that students' descriptions of what it means to take on these role identities are consistent with prior quantitative measurements of identity and gives a deeper understanding of how students are interpreting survey questions related to identity. Additionally, students' descriptions of the kinds of access to diverse STEM identities can provide ways for education researchers to help students develop stronger STEM identities and break down the barriers for all students to have access to rewarding and economically valuable careers.

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