Bridging the Virtual Divide: The Influence of Diverse STEM Role Models on the STEM Identity of Cyber School Students

by

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In cyber charter schools, middle-school students face many barriers to developing STEM identity. My theory of improvement was to address sense of belonging in a large virtual classroom to develop STEM identity in my students. By utilizing diverse STEM role models that reflected my students' racial or ethnic identities and an inquiry-based approach to teaching, my intervention nurtured the development of STEM identity in my online students. Singer et al (2020, p. 2) agrees that the best way to foster STEM identity is to "focus on both diversity and sense of belonging, which can be facilitated through authentic learning experiences." This intervention addressed both STEM identity and sense of belonging by encouraging students in underrepresented groups to participate and engage with STEM professionals who look like them in synchronous class sessions. This study shows promise for reducing the barriers to developing STEM identity online because the intervention can foster community and a sense of belonging in the virtual classroom while also teaching about STEM careers, diversity, and inclusion.

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1.0 Naming and Framing the Problem of Practice

1.1 Broader Problem Area

Online learning has been on the rise across the United States. Even before the pandemic, the United States had seen a steady increase in the number of students choosing to complete their K-12 education via online learning over the past two decades. According to the National Center for Education Statistics, during the 2013-2014 school year, there were 478 full-time virtual schools across the United States with an enrollment of 199,815 students; by the 2019-2020 school year, the number of virtual schools had increased to 691 and enrollment to 293,717 students (U.S. Department of Education, 2021). In short, virtual-school enrollment increased nearly 50% in five years. **Virtual schools** are defined as those that "deliver all curriculum and instruction via the internet and electronic communication, usually asynchronously, with students at home and teachers at a remote location" (Molnar, 2021, p. 10). During the 2020-2021 school year, the pandemic affected the number of students learning online, in that a vast majority of students were forced into emergency remote learning, a specific term used to refer to the type of instruction delivered during the COVID-19 pandemic (Hodges, 2020). However, even when schools resumed in-person learning after the pandemic, a significant number of students remained interested in online learning. The pandemic experience served as an inadvertent booster for online learning and opened the eyes of many students and families to the possibilities of virtual schools.

According to the *Virtual Schools in the U.S. 2021* report by the National Education Policy Center, during the 2019-2020 school year, about half of all virtual schools nationwide were cyber charter schools (Molnar, 2021, p. 4).

Pennsylvania has been a standout in online learning. During the time period of 2002 through 2014, the number of students attending virtual schools in Pennsylvania increased so much that the total enrollment of all cyber charter schools ranked as the second largest school district in the state (Mann & Baker, 2019). At the time of this publication, Pennsylvania has the largest student enrollment of the states containing cyber charter schools across the country (Mann, 2019). During the 2023-24 school year, there were 14 cyber charter schools in Pennsylvania. According to the Pennsylvania Department of education (PDE),

> "A **cyber charter school** is an independent public school established and operated under a charter from PDE and in which the school uses technology in order to provide a significant portion of curriculum and to deliver a significant portion of instruction to its students through the internet or other electronic means without a school-established requirement that students be present at a supervised physical facility designated by the school, except on a very limited basis, such as for standardized testing" (Pennsylvania, 2022b).

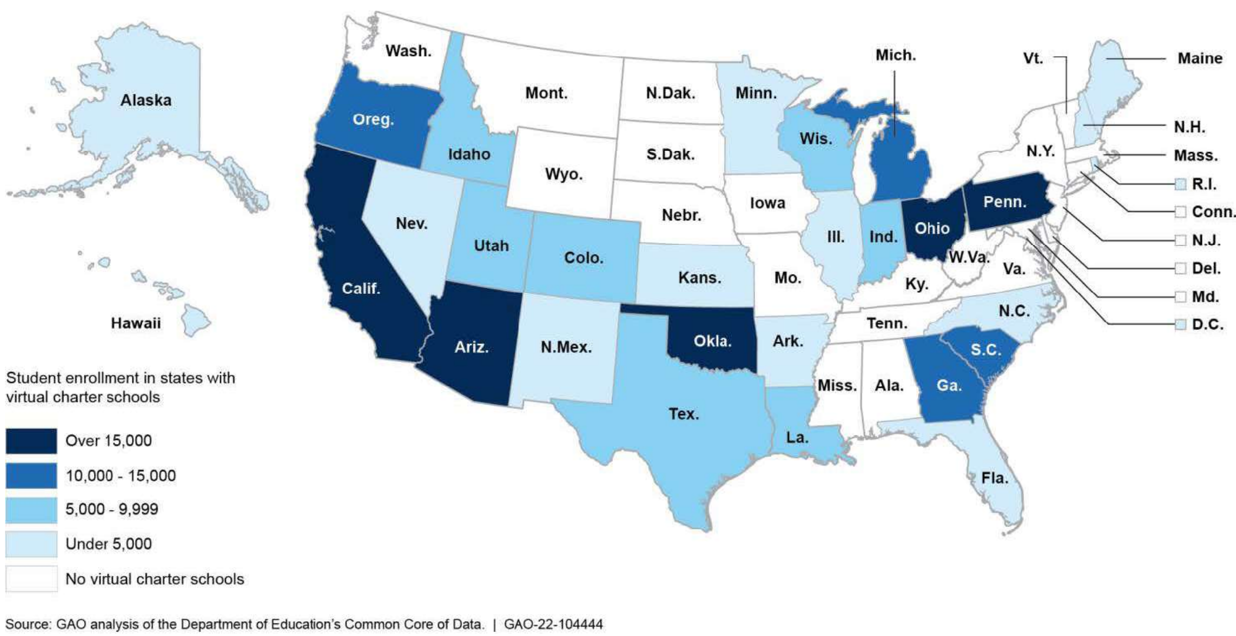

Figure 1-1 States with Virtual Charter Schools, by Student Enrollment, School Year 2019-2020

With the sudden increase in student enrollment, virtual schools had to place students in classrooms quickly. Large classroom size was a significant problem in virtual K-12 schools. The effects of high student-to-teacher ratio in the classrooms of brick and mortar (B&M) schools have been well documented. In B&M schools, workload (the number of students that teachers work with) affects teachers' morale and collegiality. It has constrained the frequency of instructional activities, the opportunity to form relationships with students and families, and the ability to work within a learning community (Laitsch, Nguyen, & Younghusband, 2021). The problems that accompany a large workload in B&M schools have remained present in virtual schools. A virtual classroom has usually been staffed by a single teacher and has had a greater student-to-teacher ratio than the typical B&M classroom. The lack of a physical space masked the problems online teachers experienced when facilitating learning with large numbers of students in virtual classrooms. Online teachers have also faced difficulties when they have had large virtual classes. Online teachers have been forced to limit their interactions with students, thereby making individualized attention difficult. The amount of grading required for large virtual classes of students can dominate teachers' workloads, which leads to less time dedicated to instruction. In their research on class size in online K-12 learning, Zhang et al state that "online class size has sometimes been called a myth, because the number of students in an online class is not a standalone factor, but intertwined with other aspects of online learning, which in turn affect student learning behavior" (2018, p. 275). The potential has existed for decreased student achievement when schools assigned too many students to a single virtual classroom. Additional factors (such as interaction, teacher experience, subject area) have not been considered by virtual K-12 schools when making these decisions. Unfortunately, there is no agreed upon number of students to enroll in a virtual K-12 classroom.

It is difficult to foster community when there are too many students in a classroom. In simple terms, a classroom community is a group of students and teachers sharing a common space and a common goal. In a classroom that has achieved this community, students feel a sense of belonging. They feel valued, accepted, and invested in their learning. Community in the classroom benefits students through increased engagement and mutual trust. Students who feel a sense of belonging in the classroom are better prepared to engage with online learning (Dolan et al., 2017). But when virtual class sizes are high, interactions between students are severely limited and impersonal. This occurs regularly in large virtual classrooms, making it easy for students to become disconnected from one another, especially without the support of in-person relationships. "Establishing mutually reinforcing relationships is essential to cultivating community in the online environment" (Dolan et al., 2017, p. 45). Students want to feel safe and welcomed in the virtual classroom. With the increase of students attending online schools, developing a classroom community and fostering a sense of belonging are at risk in large virtual classrooms.

Science, Technology, Engineering, Mathematics (STEM) education is important for students, whether they're learning online or in B&M schools. In addition to STEM content learning, STEM education encourages students to learn skills (such as problem solving, creative thinking, and collaboration) that are useful in school and for lifelong learning (Yang & Baldwin, 2020). STEM education also nurtures students' **STEM identity**, that is, "the way individuals view themselves based on a belief in their ability to utilize STEM skills and/or to become a STEM innovator or professional" (Collins & Jones Roberson, 2020). Much research has been dedicated to facilitating STEM education and nurturing STEM identity in B&M schools (Hachey, 2020), (Park-Taylor et al., 2022), (Kelley & Knowles, 2016). However, with the increase in enrollment of virtual K-12 schools, there is an urgent need for research into best practices for facilitating

STEM education in the virtual classroom and nurturing STEM identity in K-12 students that are learning exclusively online.

Middle school has been identified as a critical time for students to develop self-efficacy and consider career aspirations (Almeda & Baker, 2020). Students are learning multiple STEM subjects in greater depth, adding new subjects to their repertoire, and beginning to identify areas that interest them. However, many middle-school students in the virtual classroom cannot grasp the presence and impact of STEM in nearly every facet of their lives without the opportunity to experience engaging STEM education online (Brown et al., 2016). It is challenging to provide adequate opportunities for online students to develop problem solving, critical thinking, and collaboration skills that would be useful in any career that interests them. This is due in part to the barriers that exist in online learning environments.

Given these causes, the problem of practice I sought to address was the many barriers that middle-school students face when developing STEM identity in large virtual classrooms.

1.2 Organizational System

Reach Cyber Charter School (Reach Cyber) is a tuition-free online public school in Pennsylvania (PA). It is certified by the Pennsylvania Department of Education and open to students in Kindergarten through 12th grade state-wide. It is staffed by PA-licensed teachers. Reach Cyber's mission is to promote academic growth and build curiosity through integrated STEM opportunities, K-12 personal instruction, and career exploration (School, 2023). Their charter is based on STEM education, as indicated in their mission. The school was formed in 2016 with an enrollment of 714 students (Pennsylvania, 2022a). It experienced rapid growth in 2020 because of the pandemic and student enrollment increased ten-fold. During the 2023-24 school year, there were approximately 6,500 students enrolled at Reach Cyber in Kindergarten through 12th grade, with every PA county represented in the enrollment. Reach Cyber is subdivided into an elementary school (Kindergarten through fifth grade), middle school (grades sixth through eighth), and high school (grades ninth through twelfth). Principals and assistant principals lead teams of teachers and support staff at each of these levels.

Teachers and students at Reach Cyber interact in virtual classrooms. This online learning environment enables synchronous (live) interactions between teachers and students while they are in separate physical locations. Teachers and students never report to a physical building (except for state-testing locations across the state). Virtual classrooms utilize web-conferencing tools when teachers are leading their synchronous class sessions (referred to as "Live Class"), which are normally 40-50 minutes in duration. These class sessions are scheduled at various times throughout the normal school day. A student's school day may not be scheduled with Live Class sessions continuously. There may be hour-long breaks between Live Class sessions on a student's schedule.

Teachers and students at Reach Cyber also interact through a Learning Management System (LMS). In this online space, teachers design coursework (assignments and assessments), teach content, and assign due dates to the coursework on the LMS. Reach Cyber uses Canvas as their LMS. Students complete the coursework asynchronously. Teachers evaluate this coursework and communicate feedback to the students through Canvas. With the concept of flexible scheduling, students may complete the asynchronous coursework any time of the day and at their own pace throughout the academic semester as long as all the coursework is completed by the last day of the semester. This is a practice valued by Reach Cyber.

An important educational value for Reach Cyber is to provide optional, extra-curricular, in-person STEM events for students to attend and participate. Not only does this fulfill their charter goal of integrated STEM opportunities, but it also provides positive publicity for the school. This is an important value, since like all charter schools, Reach Cyber relies on voluntary enrollment. These in-person STEM-learning events are facilitated in various locations across the state and throughout the school year to increase access for students' and caretakers' participation. Reach Cyber has an internal department dedicated to planning and facilitating these STEM outreach events.

1.2.1 Barriers Specific to Cyber Charter Schools

Reach Cyber values supporting student growth and student success. Their vision is to inspire and nurture future success for all students (School, 2023). However, policies specific to cyber charter schools have contributed to my problem of practice – barriers to developing STEM identity in large virtual classrooms.

There are statewide policies in place for cyber charter schools that contribute to my problem of practice. Due to the flexibility of online learning, the cyber charter school attendance policy states that students are not required to attend synchronous (Live Class) sessions. Instead, attendance is based on the completion of asynchronous coursework in the LMS (Canvas). Teachers facilitate content learning in both asynchronous and synchronous formats. Given this flexibility, it is very difficult for teachers (and students) to establish classroom community when students choose the asynchronous mode of instruction exclusively. In conjunction with the attendance policy is the student engagement policy. Teachers encourage students to use their cameras, microphones, and chat features to engage in the virtual classroom but, the student engagement policy does not require students to participate in Live Class sessions if they choose to attend. When teachers don't receive input or interactions from students during Live Class sessions, it is difficult to teach.

There are structural elements in cyber charter schools that contribute to my problem of practice. Since there is not a physical space limitation, virtual class sizes can be very large. During the 2023-2024 school year, my STEM7 course had about 250 students enrolled per semester. The total enrollment was divided into four teaching sections, each with its own time slot. Each section had approximately 60 students. All 60 students were invited to attend the Live Class session in their time slot. My Live Class sessions were 45 minutes in length. If all 60 students were to attend Live Class and chose to interact, each student would have less than a minute to contribute. I would not have time to facilitate learning. It was very difficult to interact with every student given these conditions. Student enrollment in the STEM7 course fluctuated on a weekly basis due to new students enrolling and withdrawing at Reach Cyber. This transience also made it difficult to establish rapport with all students.

1.2.2 Barriers Specific to Online Learning

The online learning space is filled with distractions. Some students are tempted to plagiarize and cheat on assignments with the internet readily available to them. With flexible scheduling, some students are tempted to play games or watch videos instead of completing asynchronous coursework or attending Live Class sessions. Since students are separated physically across the state, it is easy for them to refrain from in-person social activities and not interact with classmates outside of the online learning environment.

While online learning has its benefits, there are drawbacks to being unseen. Overwhelmingly, students do not use cameras during Live Class, making it difficult for teachers to understand the emotions and thoughts of the students present. Teachers typically only see students' names and not faces during Live Class sessions. In large virtual classrooms, there are too many students for teachers to learn each student's gender, race or ethnicity, and socioeconomic background. This means teachers may not be able to consider cultural context or background when facilitating learning. Cyber charter school policies make it possible for students to become invisible. Anonymity is reinforced by the attendance policy, the engagement policy, and large class sizes.

In a cyber charter school, where class sizes are large and face-to-face interactions are limited, practices that foster community and a sense of belonging can support the development of STEM identity in students in large virtual classrooms.

1.2.3 Positionality

My positionality as a white person has hindered my ability to completely envision the barriers for learning that existed for my ethnically diverse students every day. I was educated in predominantly White K-12 schools and graduated from large universities in the Midwest, so my experience learning as a student in classrooms with Black or African American students has been limited. Fortunately, I taught in a Title 1 school in a sizeable city in the Midwest for ten years, which allowed me the opportunity to work with diverse student populations (including African immigrants) and empathize with students living in impoverished conditions. Additionally, I have taught in different regions of the United States and at different grade levels, which has given me the opportunity to observe cultural nuances present in teaching.

Given these varied teaching experiences and my own educational background, I have developed a commitment to serve both ethnically diverse students and students in impoverished situations, two groups that face systemic barriers to developing STEM identity. Growing up in a home with working-class parents, I learned that education could help a person improve themself as an individual as well as their quality of life and economic security. My goal as an educator has been to nurture STEM identity in my students so that they would be able to pursue education for personal development and professional advancement. Knowing and utilizing STEM skills (such as problem solving, creative thinking, and collaboration) can aid middle-school students in their lifelong journey of learning, regardless of their chosen career or field of study (Sen et al., 2018).

1.3 Concerned Parties

1.3.1 Students

Identifying which parties are impacted by my problem of practice was an important step in understanding the system in which my problem of practice exists.

The demographic data of Reach Cyber students contributed to a better comprehension of the system. When students enroll at Reach Cyber, caretakers respond to questions on the application that collect students' racial and ethnic preferences. The middle-school level of Reach Cyber includes grades six through eight. During the 2022-23 school year, there were approximately 1,500 students in these three grade levels. Approximately 50% of the students identified as White and 25% identified as Black or African American, with the remaining 25% identifying as a combination of Hispanic or Latino, and Multi-racial (two or more races as identified by the individual). This stood in contrast to the teachers, 93% of whom were White and only 4% were Black or African American. This demonstrated the disparity in representation between teachers and students. Special education students had been assigned Individualized Educational Programs (IEPs) to customize their learning. About 25% of the middle-school population were students with special needs. This percentage was consistent across the three grade levels. Of the 25%, more male students (both Black or African American and White) were assigned IEPs than female students. English Language Learners were a fractional minority, making up less than 1% of the student population.

Like other cyber charter schools in Pennsylvania at the time, the academic achievement data was not promising for Reach Cyber. On the 2022-23 Pennsylvania achievement tests, the mathematics proficiency rate was only 7.6% overall for the middle school at Reach Cyber. When considering internal demographics, a concerning statistic is that 10% of White students were proficient in mathematics, compared to only 2.7% of Black or African American students. In English Language Arts, the proficiency rate was 28% overall for the middle school at Reach Cyber. Again, fewer Black or African American students achieved proficiency on the tests than White students; 32% of White students were proficient, compared to only 18.5% of Black or African American students.

It's important to recognize additional factors when comprehending the system in which my problem of practice exists. During empathy interviews with seventh-grade students, many respondents expressed the importance of factors outside the online learning environment. These students liked to do things with their minds and bodies. They enjoyed building, creating, and exploring. They were curious and deep thinkers. They wanted to better understand their world, and therefore they researched and learned how things work. For middle-school students, socialization is important. Interactions with their peers were sometimes in person through sports or clubs, and sometimes online through gaming and groups. However they chose to do so, socializing with others was important to these students. Interviewees said they felt important when they belonged to a group, and that they liked the feeling of being a part of a group.

As a result of empathy interviews, a clearer understanding of STEM identity emerged. All students interviewed (as part of this sample) were all able to identify a STEM career that they might enjoy someday. They desired lucrative jobs, and they wanted to be happy in their jobs. One student said, "I want to be an engineer. It would be fun and a high-paying job. Plus, I'd get to learn about different things." Another student commented, "I want to be a financial advisor. I like the industry and I can make friends there." Friendships and happiness along with success in their jobs was important to them. When asked about her emotions regarding having a STEM career, one student said, "I would feel like a professional and happy that I accomplished my goal." Another student shared, "It will be an exciting feeling when I have that career, a dream come true." The students anticipated feeling proud of themselves for accomplishing the goal of getting their dream jobs. One student said, "It would be great to be paid to look at space!" Another student remarked that "I know a lot about computers and I'm good in that section of technology. I could fix a computer. I would like to be around computers and helping people." These students idealized STEM careers that would embody their personal interests and empower them through professional success.

1.3.2 Teachers

The middle-school teachers at Reach Cyber are PA-licensed according to the same standards in B&M schools. During the 2022-23 school year, there were 91 staff members at the middle school and 78% of them were female. These demographics were similar to teachers in B&M schools nationally (Statistics, 2020). Of the female staff members at Reach Cyber, 41% were teachers of Science, Technology, Engineering, and/or Mathematics classes.

Information shared through semi-structured interviews with Reach Cyber staff members emphasized the need for both teachers and students to be safe in the virtual classroom. In the past school year, Reach Cyber teachers had experienced incidences of uninvited users disrupting synchronous class sessions with pornographic and/or hate images and threatening language. When asked to define classroom community, one teacher responded, "It's a place where these students and teachers feel safe." She described the ideal virtual classroom as a place where students are interacting and feel accepted in a safe environment. She shared about a teaching situation with nearly 200 students in a virtual classroom. "High class size is not good for building community." The students in this large virtual classroom were passive learners and seemed disconnected from one another.

Large class size can limit creativity in the instructional activities that can be facilitated in a large virtual classroom. The level of student engagement is negatively impacted by large class size. The workload of evaluating large numbers of student assignments and assessments also affects teachers' time to design engaging lessons in the large virtual classroom.

The issues of large class size and the need to feel safe can impact a teacher's ability to promote a sense of belonging in the virtual classroom. Without feeling like a valued member of a community, a student may struggle to develop a STEM identity.

1.4 Statement of the Problem of Practice

A virtual school is a complex system with many elements interacting in an online environment. Due to this complexity, a variety of problems arise that may be investigated. I taught a middle-school elective course called STEM7 course. I facilitated learning through asynchronous coursework which explored concepts related to engineering (such as the history of inventions and innovations). I also facilitated learning through synchronous Live Class sessions which explored STEM careers. I designed the STEM7 course to provide students with opportunities to develop their own career identities, particularly ones involving STEM. I struggled to establish a classroom community where students felt welcomed and accepted when the virtual classroom had a large student enrollment. The passive nature of the cyber charter school's attendance and engagement policies made it difficult to nurture students' STEM identity in Live Class sessions. These factors contributed to my problem of practice: middle-school students face many barriers to developing STEM identity in large virtual classrooms.

This was an actionable problem of practice because the problem was within my sphere of influence. As a teacher, I could impact my students' STEM identity through virtual activities facilitated in my STEM7 course and in a reasonable time frame. The need to nurture STEM identity in students despite the barriers present in online learning is consistent with Reach Cyber's charter goals for STEM education. The shortage of people of color and women in STEM careers is well-documented (Blustein et al., 2022; Park-Taylor et al., 2022). Given these conditions, I conceptualized STEM identity in the large virtual classroom in a way that made it improvable and open to change.

1.4.1 Rationale

My goal for the STEM7 course was to nurture students' STEM identity despite these barriers. In my role as classroom teacher, I could influence change in the system through the structures of asynchronous coursework and synchronous classroom strategies to reduce barriers that hinder the development of STEM identity. The inclusive nature of this goal was to support students in racial or ethnic groups traditionally underrepresented in STEM, including individuals who self-identified as Black or African American, Hispanic or Latino, and/or Multi-racial. These students were referred to as "**students in underrepresented groups**" throughout this study. It was important to design activities to attract these students in underrepresented groups specifically to participate in the intervention.

This goal addressed systemic inequity present in online learning environments. One example of inequity is the lack of access to physical resources for online students. STEM identity development often involves exploring various aspects of STEM through projects and experimentation. Online students are unable to participate in STEM learning activities that utilize STEM resources (like science equipment or robots) when the resources are not present in their places of learning. Another example of inequity is the absence of an in-person learning community. In traditional classroom settings, one way to develop STEM identity is to facilitate problem-solving activities with groups of students (Paul et al., 2020). This is a challenge in a virtual classroom because hands-on activities and group work are not as accessible to all students learning online. The lack of access to physical resources and group learning impact online students' ability to develop a STEM identity.

1.5 Review of Supporting Knowledge

As a result of the pandemic, more K-12 students are attending virtual schools than ever before. The first section of the review of supporting knowledge examined the background of virtual schools to better understand the students in virtual classrooms. The guiding question for this section was: *What are the characteristics of students who attend virtual K-12 schools?*

The second and third sections of the review of supporting knowledge examined both STEM identity and career identity in students. There is a well-documented shortage of people of color who are qualified and seeking STEM careers. To address this, schools – both B&M and virtual – should nurture STEM identity in their students. "The decision to participate in STEM fields is a longitudinal process that builds from experiences in middle school, which carries into decisions during postsecondary education and employment after college" (Almeda & Baker, 2020). The guiding questions for these two sections were: *How are STEM identity and career identity defined?* and *What strategies can be used to nurture the development of STEM identity and career identity in students?*

The final section of this review examined strategies that encourage interaction in the virtual classroom. The guiding question for this section was: *What are the conditions that promote social interaction in online learning?*

1.5.1 Characteristics of Students Attending Virtual K-12 Schools

This section described general characteristics of students in virtual K-12 schools. A study from Ohio revealed that students in online schools were more likely to qualify for the federal free and reduced lunch program and less likely to participate in gifted education (Ahn & McEachin, 2017). A study from Tennessee revealed no difference between males and females or between White and non-White subgroups of students in academic achievement in online schools. This study also found that students in middle school outperformed all other students (in grades 7-12) in this study (Whitinger, 2013). A study of Indiana's virtual charter schools revealed a negative impact on the academic achievement of the average student who switched from a B&M public school into a virtual charter school (Fitzpatrick et al., 2020). A study of charter schools in PA revealed that students attending online charter schools experienced over 100 fewer days of instruction in math and reading, respectively, than students attending B&M charter schools (CREDO, 2019). The *Online Charter School Study* from CREDO revealed that students in online charter schools spend an average of two years in an online school before transitioning back to B&M public school (Woodworth et al., 2015). The National Education Policy Center's *Virtual Schools in the U.S. 2021* report found fewer special education students and English language learners than the national average (Molnar, 2021) attended online schools.

Students attending virtual K-12 schools have a range of motivations for choosing this mode of instruction. According to a 2016 report created by The Foundation for Blended and Online Learning and the Evergreen Education Group, students reported that they chose virtual K-12 schools for a variety of reasons including academics, social-emotional health, safety, personal interests, and life circumstances (Learning, 2017). In the report, flexibility in scheduling, innovative approaches to learning, and personalization were also reasons cited by students for attending virtual schools. Most of the innovative approaches mentioned in the report (such as increased parent involvement and using a combination of online instructional materials and adaptive software) are utilized by Reach Cyber Charter School.

1.5.2 Defining STEM Identity and Career Identity

For this study, it was important to define both STEM identity and career identity in the research. When considering career identity, scholars have likened the concept to a narrative, similar to a life story (Meijers & Lengelle, 2012). It is composed of episodes (career-related events) that have significance to a person. The activities that occur during these events help the person construct their own career identity. These events occur throughout a person's life, and middle school is an ideal time for these events to begin forming career identity in students.

There are four components of STEM identity: interest, competence, self-recognition, and recognition by others. If STEM instruction is perceived as useful (interest) to their lives by students and they are confident in their STEM ability (competence), students are likely to shift their identity to be oriented to STEM careers (Brown et al., 2016). If students envision themselves in a STEM career, they are more likely to develop an identity that aligns with STEM professionals (Kang et al., 2019). This supports the practice of students' recognizing potential in themselves (self-recognition). A fourth important aspect is for students to be recognized by others (recognition by others) for their performance in STEM subjects. These practices embody the four components of STEM identity: interest, competence, self-recognition, and recognition by others.

1.5.3 Strategies to Develop STEM Identity and Career Identity

Given the right preparation, classroom activities can foster the development of middle-school students' STEM and career identity. First, teachers can design hands-on learning experiences that will pique students' interest in STEM disciplines to nurture their STEM identity. In this way, students become more competent in their abilities (Steinke, 2017). Second, teachers can use pictures or images of STEM professionals that look like the students in their classrooms. This fosters the self-recognition aspect of STEM identity, that is, seeing STEM professionals who look like them (Collins & Jones Roberson, 2020). Third, teachers can utilize STEM professionals with similar ethnic backgrounds as guest speakers or role models in their classrooms. This practice can foster students' sense of belonging or membership into a group (recognition by others) which can cultivate STEM and career identity in students (Kim et al., 2018). These three examples are practices that can nurture both the development of STEM and career identity in middle-school students.

There are also conditions that promote the development of career identity in students, particularly identity in STEM careers. To begin, if STEM instruction is perceived as useful by students or having a personal impact on them, students are more likely to shift their identity to be oriented to STEM careers (Brown et al., 2016). If students envision themselves in STEM careers, they are more likely to develop an identity that aligns with STEM professionals (Kang et al., 2019). Membership into the social group of STEM professionals is also important. When students have a sense of belonging in STEM fields, they are likely to envision themselves as STEM professionals in the future (Kim et al., 2018). Utilizing ingroup role models as social capital can foster this sense of belonging and encourage STEM career identity. In other words, when students are exposed to STEM professionals who look like them, their career trajectories can be positively affected and their STEM career identity can be nurtured (Saw, 2020).

1.5.4 Conditions that Promote Social Interaction in Online Learning

Several studies have identified conditions that promote social interaction in online learning environments. For example, a strong peer community can lead to an increase in online engagement.

When students feel a sense of community, their confidence grows and they feel supported in participating (Farrell & Brunton, 2020). Multiple methods for interacting are useful for building a community of learners. Interactions between learners, instructors, and content are useful in encouraging engagement in peer communities (Bolliger & Martin, 2018). A positive classroom climate can influence students' interactions. "Researchers found that a sense of belonging was a necessary component related to flourishing and was shown to be an issue for women and for both genders from underrepresented ethnic and racial groups in science" (Martin-Hansen, 2018, p. 5). The relationship between a sense of belonging and community is cyclical and interconnected. They reinforce and influence one another. Students need to feel a sense of belonging in the classroom. Without this, they are disconnected from the learning community (Laing, 2010).

A strong peer community can lead to an increase in participation and therefore, attendance. When students feel a sense of community, their confidence grows and they feel supported in their efforts to participate (Farrell & Brunton, 2020). Having a variety of ways to interact can support collaboration that fosters community. While the definition of engagement is multifaceted, emotional engagement targets the development of community in online classrooms. "Emotional engagement encompasses positive and negative reactions to teachers, classmates, academics, and school and is presumed to create ties to an institution and influence willingness to do the work" (Fredricks et al., 2004, p. 60). Positive emotional engagement, such as helpful relationships and student-centered learning, can encourage social interactions that lead to a classroom community that fosters the development of STEM and career identity.

1.5.5 Synthesis

There are many factors to consider when nurturing STEM identity in students attending virtual schools. Fostering a sense of belonging is vital to the development of STEM identity. STEM identity is nurtured through experiences that interest students in STEM and allow them to envision themselves in STEM careers. Ingroup role models can influence students' STEM identity. Finally, creating a supportive virtual classroom community along with facilitating STEM activities that engage students can nurture STEM identity in online learners.

2.0 Theory of Improvement and Implementation Plan

2.1 Theory of Improvement and the Change

In cyber charter schools, middle-school students face many barriers to developing STEM identity. An absence of feeling connected or included is one of these barriers. My theory of improvement (see Figure 2-1) consisted of two primary drivers (classroom engagement and asynchronous learning) along with several secondary drivers and three change ideas. My theory was that addressing sense of belonging in the large virtual classroom would help students in underrepresented groups develop STEM identity.

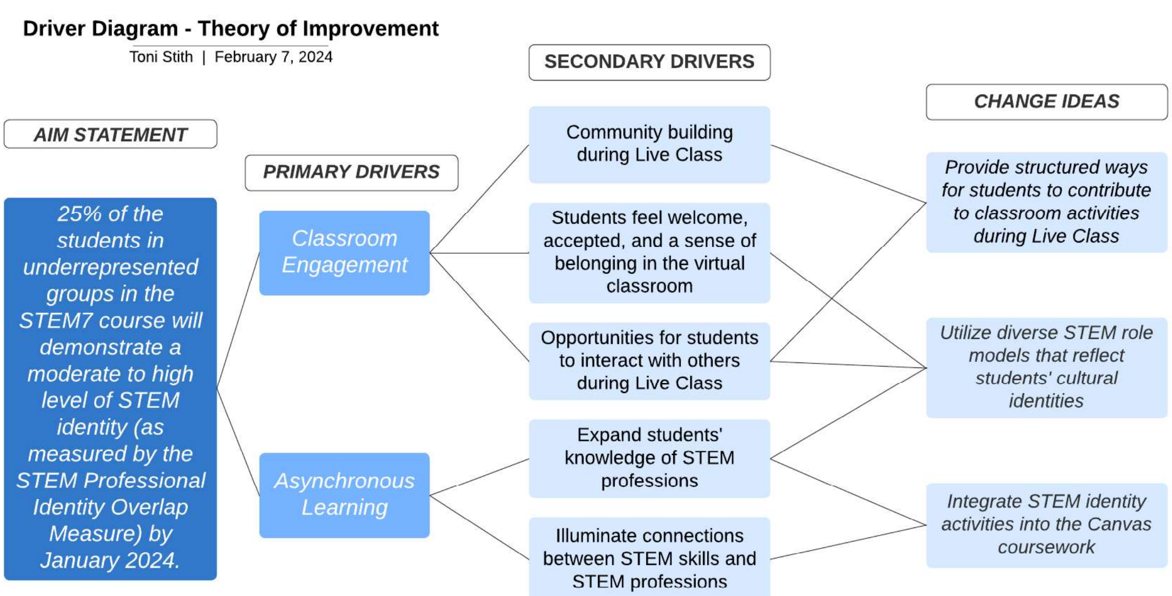

Figure 2-1 Driver Diagram – Theory of Improvement

2.1.1 Aim Statement

The aim of this theory of improvement was for 25% of the students in underrepresented groups in the STEM7 course to demonstrate a moderate to high level of STEM identity (as measured by the STEM Professional Identity Overlap Measure) by January 2024.

2.1.2 Primary Drivers

According to my theory of improvement, there are two general primary drivers that can influence STEM identity development in my online students: classroom engagement and asynchronous learning (see ‘Primary Drivers’ in Figure 2-1). The primary drivers are structures or processes in the system that can influence the aim or theory of improvement.

Classroom Engagement

When nurturing STEM identity online, one of the barriers to overcome is the cyber charter school’s engagement policy. This policy states that students are not required to participate using webcams, microphones, or chat features when instruction is facilitated by the teacher during Live Class. This was a barrier because there is learning loss without student participation. **Classroom engagement** (active involvement and/or participation during Live Class) was one of the primary drivers that could produce change in the system. By facilitating meaningful activities with students, their motivation to participate and be involved in the virtual classroom might change, increasing classroom engagement. By increasing classroom engagement with activities that nurture STEM identity, the system could change.

Asynchronous Learning

Asynchronous learning ("online coursework" that students complete on their own time in Canvas) was an element of the system that could be used to achieve my goals. Reach Cyber placed importance on asynchronous learning and communicated this importance to the students by basing students' STEM7 course grade on it. By integrating instructional activities that develop STEM identity into online coursework in Canvas, STEM identity might increase in the students and the system may change. Importance has been placed on developing STEM identity that is equal to the importance of earning a passing grade in the STEM7 course. With this in place, students' motivation to complete STEM identity activities in Canvas might increase and positively influence the system.

2.1.3 Secondary Drivers

According to my theory of improvement, there are multiple secondary drivers that could function as levers for change in the areas of classroom engagement and asynchronous learning (see 'Secondary Drivers' in Figure 2-1). These secondary drivers are opportunities within each primary driver where changes might influence the aim or theory of improvement.

Classroom Engagement

Engagement is a good driver for change because teachers could use a variety of strategies to meet the needs of online students during Live Class sessions. The following two virtual classroom strategies might lead to an increase in classroom engagement, which could lead to an increase in my students' STEM identity development. First, increasing opportunities for building classroom community might lead to an increase in participation during Live Class sessions. Secondly, creating a classroom that promotes acceptance and a sense of belonging has the potential to encourage students in underrepresented groups to engage in virtual classroom activities (Gray et al., 2018). When students are interacting with others during Live Class sessions, students' attitudes about learning might change. Students feel valued when teachers are actively providing them with feedback (Peacock et al., 2020). These approaches could impact the primary driver of classroom engagement which could lead to an increase in STEM identity.

Asynchronous Learning

Asynchronous learning is an area that could produce change in the system. By creating activities that expand students' knowledge of STEM professions, students in the STEM7 course might be motivated to complete online coursework. These activities might lead to an increase in asynchronous learning which could lead to an increase in my students' STEM identity development. Through the use of STEM-specific videos, websites, or pictures embedded as learning activities in Canvas, students are able to learn about the roles and responsibilities of various STEM professions on their own time. Illuminating connections between STEM skills and STEM professions in asynchronous learning could help students make personal connections with STEM professions. These instructional approaches might positively influence the primary driver of asynchronous learning in the STEM7 course.

2.1.4 Change Ideas

To support this theory of improvement, three change ideas are suggested (see 'Change Ideas' in Figure 2-1). These change ideas could address some of the barriers students face when developing STEM identity in the large virtual classroom.

Change Idea #1

Classroom engagement might be impacted when students are provided structured ways to participate in virtual classroom activities during Live Class sessions. Training students to engage with one another in ways that make everyone feel welcome can promote classroom engagement (Dolan et al., 2017). Using this strategy, students might find the Live Class experience more meaningful and relevant. It has the possibility of increasing the number of students involved in the virtual classroom while also developing STEM identity in students.

Change Idea #2

By utilizing diverse STEM role models, students see their cultural identities reflected in adults. This might produce change as well. The opportunity to develop STEM identity is increased when interactions between students and STEM role models are authentic (Hughes et al., 2013). Students could design questions that express their interests and ask diverse STEM role models their questions during Live Class. The potential exists to impact students' STEM identity and encourage students to consider STEM professions in their future by using this approach.

Change Idea #3

Integrating activities that could develop STEM identity into the online coursework could result in improvement toward the aim. These integrated activities could be specifically designed for STEM identity development. This idea has the potential to impact the system because it can reach all STEM7 students through the LMS and Canvas. Unfortunately, students were not required to attend Live Class sessions so improving the instructional practices during Live Class sessions alone could not change the system. By implementing change through asynchronous learning, the system has a better chance of being impacted.

2.1.5 Conclusion

The change idea used in this study was to utilize diverse STEM role models who reflected students' cultural identities to address sense of belonging in the virtual classroom. This change idea was integrated into asynchronous coursework (primary driver) in order to reach all STEM7 course students. I designed Canvas activities that expanded students' knowledge of STEM professions (secondary driver). These activities utilized diverse STEM role models (change idea) to develop STEM identity.

Expanding on my previous description, my theory of improvement was that utilizing diverse STEM role models who reflected my students' cultural identities in activities designed to expand students' knowledge of STEM professions would develop STEM identity in middle-school students in the large virtual classroom.

2.1.6 PDSA Cycle

The intervention for my Plan-Do-Study-Act (PDSA) cycle was based on the change idea of using diverse STEM professionals as role models in my virtual classroom, specifically utilizing STEM professionals as guest speakers in Live Class sessions. This intervention complemented the objectives (exploring STEM careers) of the STEM7 course. Students engaged in identity work as part of the designed curriculum for the STEM7 course. This intervention addressed both STEM identity and sense of belonging by encouraging students in underrepresented groups to participate and engage with STEM professionals who look like them in Live Class sessions.

In the first PDSA cycle, the role model was a Multi-racial female engineer. Students attending Live Class sessions participated in the initial lesson. The intervention began with an initial lesson on engineering and a brief activity that taught students how to pose questions. Towards the end of the Live Class session, I prompted students to generate questions about the field of engineering and about the engineer herself. I posted her photo on the screen so that students were able to visualize the person who would be answering their questions. Students entered their questions onto the Mentimeter website.

Following the initial lesson, I communicated with the engineer. I emailed the student-generated questions from the Mentimeter website to her and explained the desired format of her presentation for my students. The format of the presentation required the engineer to provide background on her STEM journey and job responsibilities for the first half of the class time and answer the students' questions (sent via email) for the second half of the presentation.

One week later, the engineer presented to the students who attended Live Class on that date. Students from all four sections of the STEM7 were invited to attend this Live Class through calendar events on Canvas. After a short introduction by me, the engineer facilitated her presentation. After her presentation, students had the opportunity to ask the engineer questions via their microphones or the chat box. Students who attended the presentation during Live Class were asked to take two polls: one before the engineer's presentation and one after the presentation. This poll was the STEM Professional Identity Overlap Measure and was administered using Zoom poll features. After the presentation and polls, students were strongly encouraged to log into Canvas and complete a survey called "STEM Profession Assignment" (see Sec 2.1.8). This survey was part of the STEM7 course asynchronous learning. In order for this intervention to reach all students in the STEM7 course, the recording of the engineer's presentation was included in the opening paragraph of the STEM Profession Assignment in Canvas. I assigned points to the STEM

Profession Assignment which signified that viewing the recording of the engineer's presentation and completing the survey were requirements for completing the STEM7 course.

Data collection began after the intervention concluded. I summarized the qualitative data found in surveys. I coded the student-generated questions that were asked before and after the engineer's presentation. I then analyzed data to determine if the change idea (using diverse STEM role models in the virtual classroom) was an improvement (developing STEM identity in students) in the system (STEM7 course). Any evidence of STEM identity development in the survey responses could indicate an improvement. The quantitative data (responses to survey statements and responses to the polls using the STEM Professional Identity Overlap Measure) would also be analyzed to determine if a change has occurred.

It was my intention to complete four PDSA cycles in the first semester of the 2023-24 school year, approximately one cycle per month. Each PDSA cycle would focus on a different content area in STEM: Science (Forensic Science), Technology (Cyber Security), Engineering (Process Engineering), and Mathematics (Finance). I compared the qualitative and quantitative data from each of the four cycles to determine if this intervention produced a change in the system.

This intervention had the potential for change if students engaged with the STEM professionals through questioning. When students possess a sense of belonging in STEM fields, they are likely to envision themselves as STEM professionals in the future (Kim et al., 2018) and develop their STEM identity.

2.1.6.1 Participants

The participants for this intervention were seventh-grade students enrolled in the STEM7 course during the fall semester of the 2023-24 school year. These students attended Reach Cyber Charter School virtually and were situated across the State of Pennsylvania. I recruited students to participate in this intervention by encouraging them to attend the two Live Class sessions associated with the STEM professionals' presentations as well as other Live Class sessions. Based on my experience teaching middle-school students, I explicitly promoted the experience with customized social media graphic templates (see Figure 2-2 for an example) to attract students' attention. These graphics were displayed in Canvas announcements and on STEM7 Live Class presentation slides for the week prior to the presentations.

Figure 2-2 Recruitment Graphic for Engineer's Presentation

A photo of the diverse STEM role model was purposely included in the recruitment graphic. This promotional effort was designed to attract students in the underrepresented groups so they could attend and engage with diverse STEM role models in my virtual classroom. This helped me reach the aim of my theory of improvement.

STEM professionals were necessary participants in this intervention. They needed to be role models in my virtual classroom. I needed diverse STEM professionals, ideally from the underrepresented groups similar to my students' ethnic and cultural identities. The STEM role models needed to support the equity and inclusion goals of the intervention. They needed to be skilled online presenters, willing to share professional information, as well as some personal information in order to answer students' questions. I needed to secure one role model for each of these STEM areas: Forensic Science, Cyber Security, Process Engineering, Finance.

2.1.6.2 STEM Survey

I used the term 'STEM Profession Assignment' in Canvas to indicate to students that completing the assignment was a requirement for the STEM7 course. I was hopeful this would motivate students to complete it. The STEM Profession Assignment (or STEM survey) was created using four items from a STEM Career Interest Survey (Kier et al., 2014) and three items from an online survey "to assess their [students'] perceptions of STEM media role models" (Steinke et al., 2022).

There were two sections in the survey. Section one contained four statements that students agreed or disagreed with. Section two contained three open-response questions.

The four items in section one (from the STEM Career Interest Survey) were:

1. I am able to do well in activities that involve Engineering.
2. I plan to use Engineering in my future career.
3. I am interested in careers that use Engineering.
4. I would feel comfortable talking to people who work in Engineering.

The three items in section two (from the above-referenced online survey) were:

1. What is one new thing you learned about the engineer?
2. Which part of the engineer's job did you like the best? Why?
3. What was the most important new thing you learned about engineering from the presentation?

An important task was to devise ways to motivate students to attend the presentation and complete the survey afterwards. I needed these completed surveys to provide me with possible evidence of the development of STEM identity. Based on previous years' experience teaching the STEM7 course, students were going to need encouragement to write lengthy and meaningful answers to open-response questions on the survey.

2.1.6.3 Predictions

I predicted that the intervention would develop STEM identity in my students because they learned about STEM professions and, more importantly, about the characteristics of people who are STEM professionals. I predicted that the intervention activities would develop STEM identity in STEM7 students as demonstrated by poll responses and survey responses.

2.1.7 Inquiry Questions

Inquiry questions drove the PDSA cycle and subsequent iterations of the intervention. These questions helped me determine how influential the diverse STEM role models were in the development of STEM identity in STEM7 students. The questions also helped me to refine the intervention based on what seemed to be "working" and "not working." The inquiry questions were:

1. *In what ways did the presentation by the STEM role model affect the development of STEM identity in my students?*
2. *How did student-generated questions support the development of STEM identity?*
3. *What evidence was there of STEM identity development in my students' survey responses?*

2.2 Methods and Measures

2.2.1 Outcome Methods and Measures

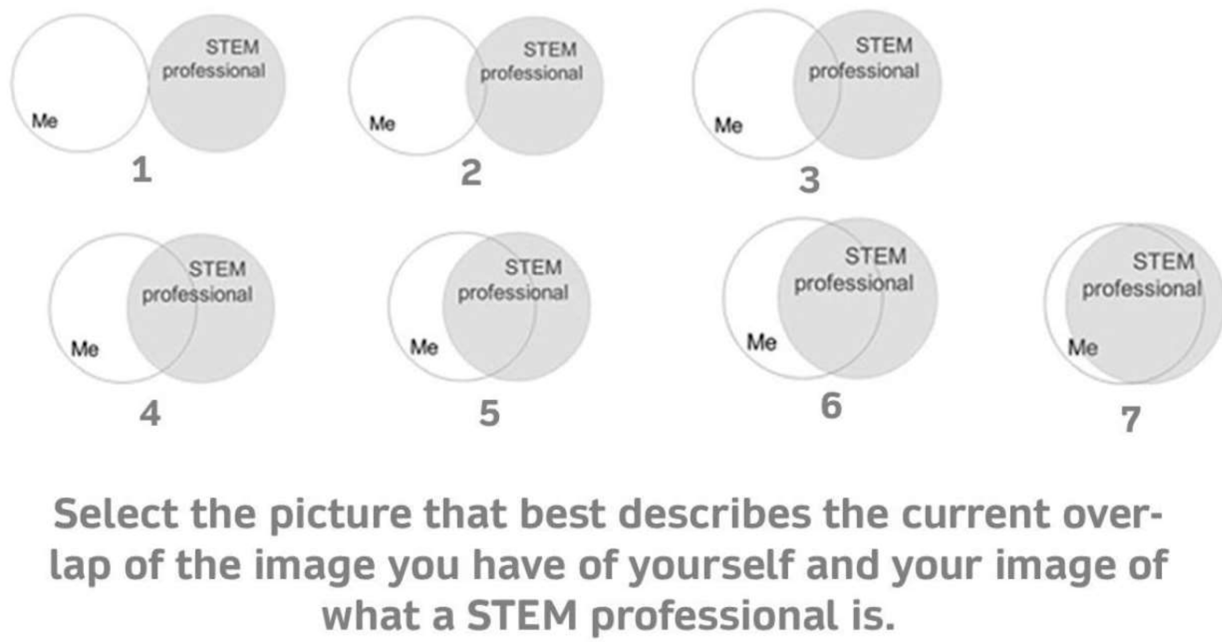

Figure 2-3 STEM Professional Identity Overlap Measure

The outcome measure of the aim statement was directly related to the STEM identity language used in the aim statement (Perry, Zambo, & Crow, 2020). The aim of this theory of improvement was for 25% of the students in underrepresented groups in the STEM7 course to demonstrate a moderate to high level of STEM identity (as measured by the STEM Professional Identity Overlap Measure) by January 2024. This outcome measure was based on the 7-point pictorial scale (see Figure 2-3) that assessed the degree of overlap students had with themselves and their image of what a STEM professional was (McDonald et al., 2019). According to its creators, the STEM Professional Identity Overlap Measure "allows for repeated assessments that are not taxing for the individual being assessed, thereby providing a 'snapshot' of the individual's identity at a particular moment, and enabling researchers and teachers to track how students' STEM identity evolves over time" (McDonald et al., 2019, p. 4). The numbers (see Figure 2-3) were assigned lowest (one) to highest (seven) according to the level of overlap in the two circles. For the purpose of this study, the top row of overlapping images (numbered one, two, and three) was considered low STEM identity. The bottom row of overlapping images was considered moderate (numbered four and five) and high (numbered six and seven) STEM identity.

To measure improvement towards the aim, I used the STEM Professional Identity Overlap Measure as a poll. Students responded with the numbers one through seven on the pictorial scale that referenced overlapping circles. This poll was distributed to all STEM7 students through Canvas at both the beginning of the semester and the end of the semester, and the numeric data was gathered electronically. Each time the poll was administered, the data was then compiled to determine the percentage of students who demonstrated a moderate to high STEM identity. Canvas also collected demographic data which allowed me to parse out the data for STEM7 students in underrepresented groups. This helped me determine if the aim had been met. When analyzing this data, I used frequency distributions to determine the percentage of students in the STEM7 course that demonstrated a moderate to high STEM identity at the beginning of the semester and the same percentage at the end of the semester.

2.2.2 Driver Methods and Measures

Classroom Engagement

The STEM Professional Identity Overlap Measure was also utilized as a poll during Live Class sessions. I administered the poll before the STEM professional delivered the presentation, as well as after the presentation had concluded. I utilized the Zoom poll feature to electronically gather this data. I exported the data to an Excel spreadsheet and compared the two data sets from the two polls. This measure helped to determine if the secondary driver (expanding students' knowledge of STEM professions) was impacting the primary driver of classroom engagement.

There were some limitations to this approach. Reach Cyber's attendance policy states that students are not required to attend Live Class sessions. Therefore, students might not have attended one or more of the STEM professional's presentations over the entire intervention. Reach Cyber's engagement policy also states that students are not required to engage during Live Class sessions. Therefore, students may have attended the STEM professional's presentation but decided not to participate in either the before the presentation poll or after the presentation poll during Live Class. Due to this limitation, the number of students that completed both the before and after polls might not represent all the students involved in the intervention.

When analyzing poll responses over multiple intervention cycles, I used frequency distribution tables to analyze and compare the data. This protocol aligned with the inquiry question: In what ways did the presentation by the STEM role model affect the development of STEM identity in my students? Considering the limitations of the attendance and engagement policies noted above, an increase in the percentage of students with a moderate to high STEM identity from before the presentation to after the presentation might indicate that a change had occurred.

A STEM professional's presentation was used in all four PDSA cycles, and the STEM Professional Identity Overlap Measure was utilized for each cycle. For each intervention cycle, the two sets of poll responses were evaluated to determine if a change had occurred.

2.2.3 Process Methods and Measures

Classroom Engagement

The change idea for my theory of improvement was to utilize diverse STEM role models in activities who supported the development of STEM identity in my students. These role models facilitated presentations on their STEM professions during Live Class sessions in my virtual classroom. Before and after these presentations, students could ask questions to expand their knowledge of STEM professions (secondary driver). These questions were the basis for the first two process measures. One measure was the questions asked before the presentation. The second measure was the questions asked after the presentation. The question data was gathered electronically. To collect the question data before the presentation, students entered questions directly onto the Mentimeter website during Live Class session. I downloaded the questions from the Mentimeter website and transferred them to an Excel spreadsheet. To collect the question data after the presentation, I viewed the recording and read the chat log to locate students' questions asked through the microphone and/or chat box. Then, I typed these questions into an Excel spreadsheet.

When analyzing both sets of questions, I looked for evidence of language that suggested the development of STEM identity through content analysis. This protocol aligned with the inquiry question: How did student-generated questions support the development of STEM identity? Evidence of STEM identity language would determine if a change had occurred.

Asynchronous learning

The next two process measures were used to determine the intervention's impact on asynchronous learning. After the STEM professional had facilitated the presentation during Live Class, students completed the STEM Profession Assignment (survey) in Canvas. A recording of the presentation was available along with the survey in Canvas. (This strategy was an attempt to reach all students in the STEM7 course through asynchronous learning. It was expected that students would view the recording of the STEM professional's presentation and complete the survey). There were two sections in the survey and each section was the basis of one measure.

The first section of the survey consisted of four statements. The data for these Likert-scale survey statements were gathered electronically using Canvas. Canvas automatically recorded the numeric responses to the survey statements and tabulated the number of responses in each survey. When analyzing this ordinal data, I used frequency distribution tables and measures of central tendencies (mean and mode) to describe the responses after each presentation. I compared and described this data across the four intervention cycles. This protocol aligned with the inquiry question: What evidence was there of STEM identity development in my students' survey responses? Each statement was aligned to a component of STEM identity. An increase in the Likert-scale values of the survey responses over multiple cycles would determine if a change had occurred.

The second section of the survey consisted of three open-response questions. I examined the language used in the students' answers to these open-response questions as the basis for the process measure. The data for the open-response responses was gathered electronically through Canvas. When analyzing these open-ended responses, I looked for evidence of language that suggested the development of STEM identity. This protocol aligned with the inquiry questions: What evidence was there of STEM identity development in my students' survey responses? Evidence of STEM identity language determined if a change had occurred.

2.2.4 Balancing Methods and Measures

“Balance measures help the scholarly practitioner see if the change they have introduced has in fact been an improvement for the whole system or if it has cost the system” (Perry et al., 2020, p. 108). The data needed to understand if my theory of improvement was costing the system would come from the STEM7 students who were not in underrepresented groups. I calculated the percentage of these students that demonstrated a moderate to high level of STEM identity using the STEM Professional Identity Overlap Measure. This balancing measure was used to determine if designing activities that attempted to meet the aim statement were benefitting all the students in the STEM7 course. It was necessary to collect this data at the beginning of the semester and the end of the semester. The balancing measure of this intervention was the percentage of STEM7 students – not in underrepresented groups – that demonstrated a moderate to high level of STEM identity.

2.2.5 Conclusion

As demonstrated in Table 1, I utilized a variety of system measures to determine if the change idea (utilize diverse STEM role models) impacted the secondary driver (expand students’ knowledge of STEM professions), which impacted the primary drivers of classroom engagement and asynchronous learning.

Table 1 Overview of System Measures

Measure	Aim Statement	Student Group
Outcome	Number of students that have demonstrated a moderate to high level of STEM identity on a 7-point pictorial scale (STEM Professional Identity Overlap Measure)	Students in underrepresented groups in STEM7 course
	Classroom Engagement	
Driver	Number of students in the Live Class during the STEM Professional presentation that have demonstrated a moderate to high level of STEM identity on a 7-point pictorial scale	Students in underrepresented groups in STEM7 course
Process	Language used in student-generated questions asked before the presentation	All STEM7 students
Process	Language used in questions students asked after the presentation	All STEM7 students
	Asynchronous Learning	
Process	Ordinal data from the Likert-scale statements on the STEM survey	All STEM7 students
Process	Language used in the answers to open-response questions on the STEM survey	All STEM7 students
	Systemwide	
Balance	Number of students that have demonstrated a moderate to high level of STEM identity on a 7-point pictorial scale	Students NOT in underrepresented groups in STEM7 course

2.3 Analysis of Data

2.3.1 Data Analysis Plan

The data analysis plan is demonstrated in Table 2. During the PDSA cycles, I conducted action research (Pine, 2008) to test my change idea to determine if my theory of improvement produced a change in the system. I collected and analyzed qualitative and quantitative data from all students in the STEM7 course. The qualitative data was in the form of student-generated questions and answers to open-response questions. The quantitative data was in the form of numeric responses to survey statements and poll responses to the STEM Professional Identity Overlap Measure.

To determine if the aim of my theory of improvement produced a change, I disaggregated the poll responses (to the STEM Professional Identity Overlap Measure) for students in underrepresented groups in the STEM7 course. This nominal data was used to analyze the outcome measure. I also disaggregated these poll responses for students **not** in underrepresented groups in the STEM7 course. This nominal data was used to analyze the balancing measure.

I used my inquiry questions to structure my data analysis plan. I primarily used descriptive statistics to analyze the quantitative data. For the qualitative data, I used a hybrid approach of coding involving both content and thematic analysis (Clarke & Braun, 2022). Developing codes, searching for themes, and identifying patterns across data sets aided in the final analysis of the qualitative data.

The data for entries from my PDSA reflection journal was gathered electronically. This occurred when I typed my reflections from the implementation of the PDSA cycle into a Word document. In these entries, I looked for evidence that aligned with my inquiry questions and used it to supplement data collection and analysis efforts.

Table 2 Data Analysis Plan

Analyses	Data Source	Time Period	Analytical Approach
Theory of Improvement	Poll results (of the STEM Professional Identity Overlap Measure) for students in the underrepresented groups in the STEM7 course (inside Canvas)	Beginning and End of Semester	Frequency Distribution T-Test Analysis
Balancing Measure	Poll results for students **not** in the underrepresented groups in the STEM7 course (inside Canvas)	Beginning and End of Semester	Frequency Distribution
Inquiry question: In what ways did the presentation by the STEM role model affect the development of STEM identity in my students?	Poll results for students in the underrepresented groups in Live Class (collected through Zoom poll)	Before and after the STEM Professionals' presentations during Live Class	Frequency Distribution T-Test Analysis
Inquiry question: How did student-generated questions support the development of STEM identity?	Student-generated questions before the presentation from all students in Live Class (collected through Mentimeter)	During the Initial Lessons in Live Class	Frequency Distribution Content Analysis Thematic Analysis
	Questions students asked after the presentation from all students in Live Class (collected through Mentimeter)	After the STEM Professionals' presentations during Live Class	Frequency Distribution Content Analysis Thematic Analysis
Inquiry question: What evidence was there of STEM identity development in my students' survey responses?	Ordinal data from the Likert-scale statements on the STEM surveys from all students in the STEM7 course (inside Canvas)	Up to one month after the STEM Professionals' presentations	Frequency Distribution Central Tendencies
	Answers to open-response questions on the STEM surveys from all students in the STEM7 course (inside Canvas)	Up to one month after the STEM Professionals' presentations	Synthesis Summarize

3.0 PDSA Results

3.1 Theory of Improvement

The aim of this theory of improvement was for 25% of the students in underrepresented groups in the STEM7 course to demonstrate a moderate to high STEM identity (as measured by the STEM Professional Identity Overlap Measure) by January 2024. However, at the beginning of the semester, the aim of this theory of improvement was already met. One possible reason for this could be the school's focus on STEM. Since STEM is part of Reach Cyber's mission statement ("To promote academic growth and build curiosity through integrated STEM opportunities, K-12 personal instruction, and career exploration"), STEM-learning activities were incorporated into all classes at all grade levels. As mentioned previously, STEM outreach in-person opportunities were open to all Reach Cyber students. Additionally, STEM-focused clubs and groups (such as Minecraft and Hydroponics) were open for participation by any Reach Cyber student. Students were receiving STEM education in multiple formats and in frequent doses throughout their school day. It is possible that the students' initial self-ratings of moderate to high STEM identity were influenced by other STEM activities provided through Reach Cyber.

With this in mind, a different analysis needed to be developed. The percentage of students in underrepresented groups with a moderate to high STEM identity would continue to be calculated at the beginning of the semester and at the end of the semester. However, any increase in the percentage (observed from the beginning of the semester to the end of the semester) could suggest that the interventions brought about a change. Therefore, the modified aim of this theory of improvement was to increase the number of students in underrepresented groups in the STEM7 course that demonstrate a moderate to high STEM identity (as measured by the STEM Professional Identity Overlap Measure) by January 2024.

To measure the aim of this theory of improvement, the STEM Professional Identity Overlap Measure was utilized. Students' STEM identity was assessed with a one-item pictorial scale from "A Single-Item Measure for Assessing STEM Identity" (McDonald et al., 2019). Students selected among a set of seven overlapping circles varying in the degree of overlap (where figure one had no overlap and figure seven had near complete overlap) to represent the current overlap students viewed between themselves and their image of a STEM professional (McDonald et al., 2019). On the STEM Professional Identity Overlap Measure (see Figure 2-3), the overlapping images numbered one, two, and three represented low STEM identity, the overlapping images number four and five represented moderate STEM identity, and the overlapping images numbered six and seven represented high STEM identity.

In order to reach all students in the STEM7 course, this poll was administered through the LMS as part of STEM7's asynchronous coursework. Using Canvas (the LMS of Reach Cyber) to collect this data presented a technical limitation because a student could select more than one numeric response in the poll. If a student selected more than one numeric response to the poll, the data was not used in this study. As a result of this limitation, 19% of the poll results at the beginning of the semester and 19% of the poll results at the end of the semester were not used.

The STEM Professional Identity Overlap Measure was utilized as a poll in two separate STEM7 assignments in Canvas. In each assignment, there was a description prior to the poll in Canvas. The beginning of semester poll was administered as part of an assignment (graded survey) with a completion grade of five points and a due date in September 2023. The poll description was placed directly above the image of the STEM Professional Identity Overlap Measure of the initial poll and read:

"STEM identity & You

> What is STEM identity? Simply put, your identity is how you think of yourself. Add STEM to this and STEM identity becomes the way you view yourself based on your ability to utilize STEM skills or become a STEM professional.
>
> STEM7 class is designed with opportunities to nurture your STEM identity. There are many STEM skills that apply to all kinds of careers: creativity, problem solving, critical thinking, and teamwork. You'll get to practice those skills in this class!
>
> Who gets to have a STEM identity? You Do!"

There was a second optional question in the assignment that allowed students to enter a text response to the question: Do you have any STEM stories to share about yourself?

The end of semester poll was also administered as part of a 5-point graded survey with a due date in January 2024. The poll description was placed directly above the image of the STEM Professional Identity Overlap Measure of the conclusion poll and read:

"STEM identity & You

> STEM7 class has provided many opportunities to nurture your STEM identity throughout this semester. STEM identity is the way you view yourself based on your ability to utilize STEM skills or become a STEM professional. Select the picture (1-7) that best describes the current overlap of the image you have of yourself and your image of what a STEM professional is."

There was a second question in the assignment that allowed the student to enter a text response to the question: What does STEM/STEAM mean to you?

3.1.1 Poll Results from the Beginning to the End of the Semester

For the purpose of this study, only the data from students in underrepresented groups was used to measure change towards the theory of improvement. During the fall semester of the 2023-24 school, there were a total of 123 students in underrepresented groups enrolled in the STEM7 course. These three subgroups of students accounted for 49% of the total number of students (250) in the STEM7 course. The largest subgroup of STEM7 students (71) was Black or African American students. The middle subgroup of STEM7 students (34) was Hispanic or Latino students. The smallest subgroup of STEM7 students (18) was Multi-racial students.

Of the total students in underrepresented groups (123) in the STEM7 course, there were 59 students who participated in both the beginning of the semester and end of the semester polls. This accounted for about half of the total number of students in underrepresented groups enrolled in the STEM7 course. The largest subgroup of participating students was Black or African American students (29). The middle subgroup of participating students was Hispanic or Latino students (21). The smallest subgroup of participating students was Multi-racial students (9).

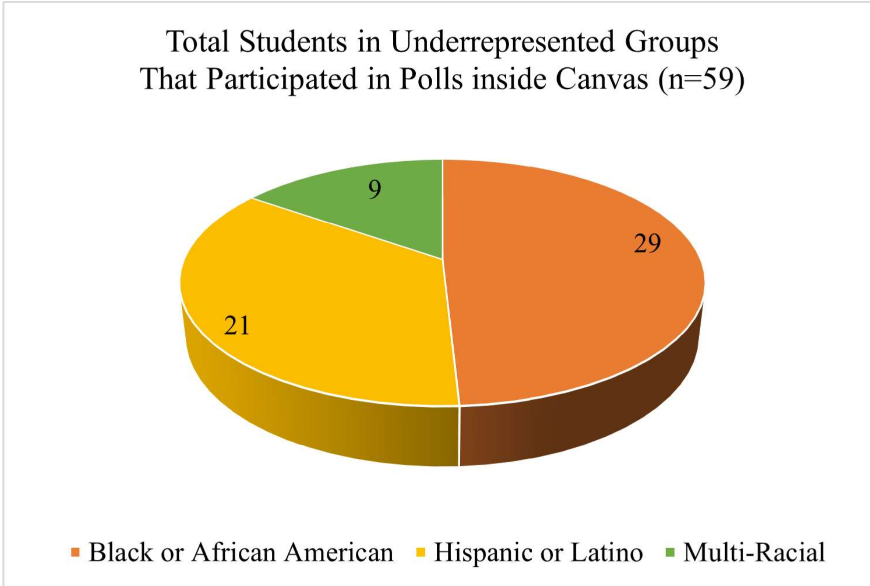

Figure 3-1 Students in Three Subgroups That Participated in Polls inside Canvas

In the graphs below, the x-axis represents the poll results from the beginning of the semester and the end of the semester, where n = the number of students in underrepresented groups that participated in both polls. The y-axis represents the percentage of students with low, moderate, and high levels of STEM identity, as measured by the STEM Professional Identity Overlap Measure.

3.1.1.1 All Students in the Three Subgroups

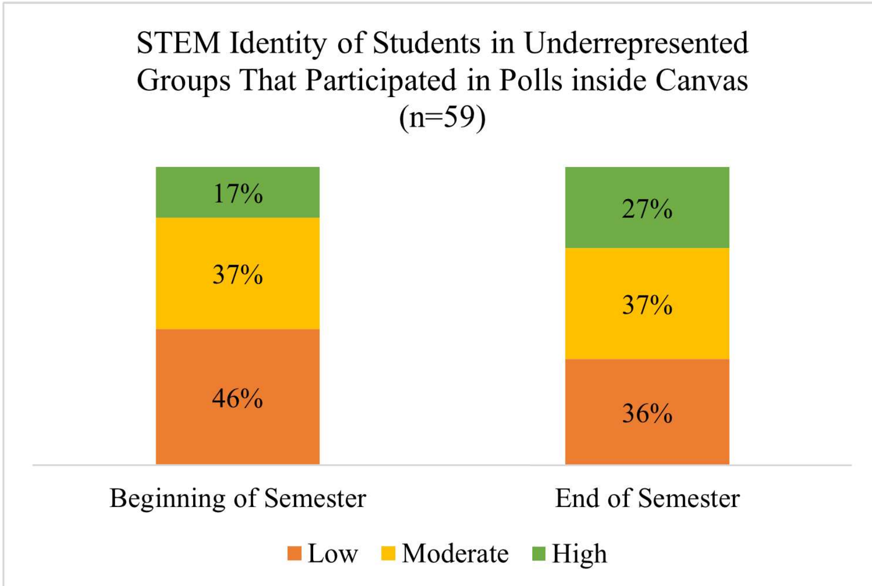

Figure 3-2 STEM Identity of Students in Underrepresented Groups

During the fall semester of the 2023-24 school year, there were 123 students in underrepresented groups enrolled in the STEM7 course. Of this group, there were 59 students in underrepresented groups that participated in the beginning of the semester poll and the end of the semester poll. There was an increase in the percentage of students in underrepresented groups who completed the polls with a moderate to high STEM identity from the beginning of the semester (54%) to the end of the semester (64%). In addition, there were 26 students from underrepresented groups who increased their self-ratings by any value from the beginning of the semester to the end.

There was a statistically significant increase in the mean self-rating of the students in underrepresented groups from the beginning of the semester to the end. The t-Test: Paired Two Sample for Means was performed using this data. The results from the beginning of the semester poll ($M = 3.8$) and the end of the semester poll ($M = 4.0$) indicated that the intervention resulted in an improvement in STEM identity, $t(77) = -2.2$, $p = .015$ (one-tail), as measured by the STEM Professional Identity Overlap Measure. This analysis suggests that the intervention (utilizing diverse STEM role models to develop STEM identity) produced a notable change in the average self-rating among students and it was unlikely to have occurred by random chance.

3.1.1.2 Black or African American Students Subgroup

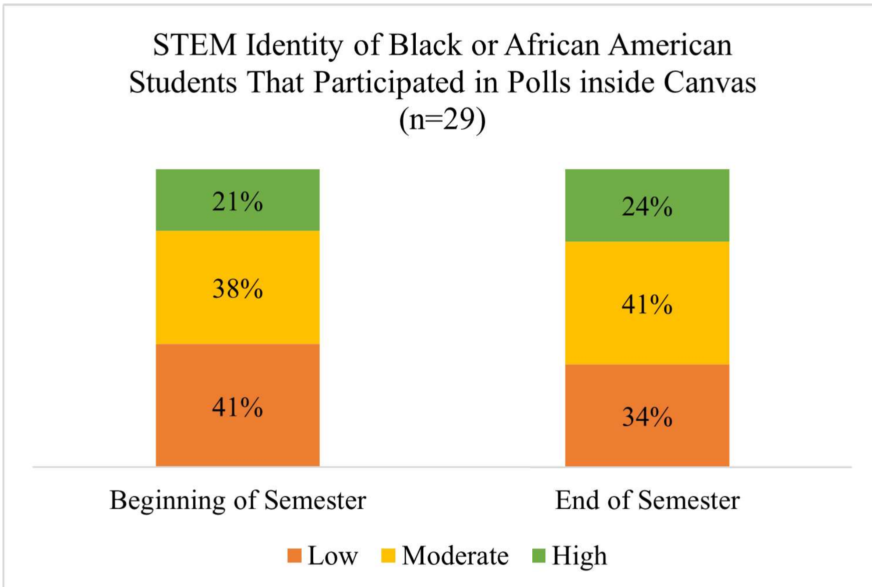

Figure 3-3 STEM Identity of Black or African American StudentsDuring the fall semester of the 2023-24 school year, there were 71 Black or African American students enrolled in the STEM7 course. Of this group, there were 29 Black or African American students that participated in the beginning of the semester poll and the end of the semester poll.

There was an increase in the percentage of Black or African American students who completed the polls with a moderate to high STEM identity from the beginning of the semester (59%) to the end of the semester (65%). In addition, there were 11 Black or African American students who increased their self-ratings by any value from the beginning of the semester to the end.

3.1.1.3 Hispanic or Latino Students Subgroup

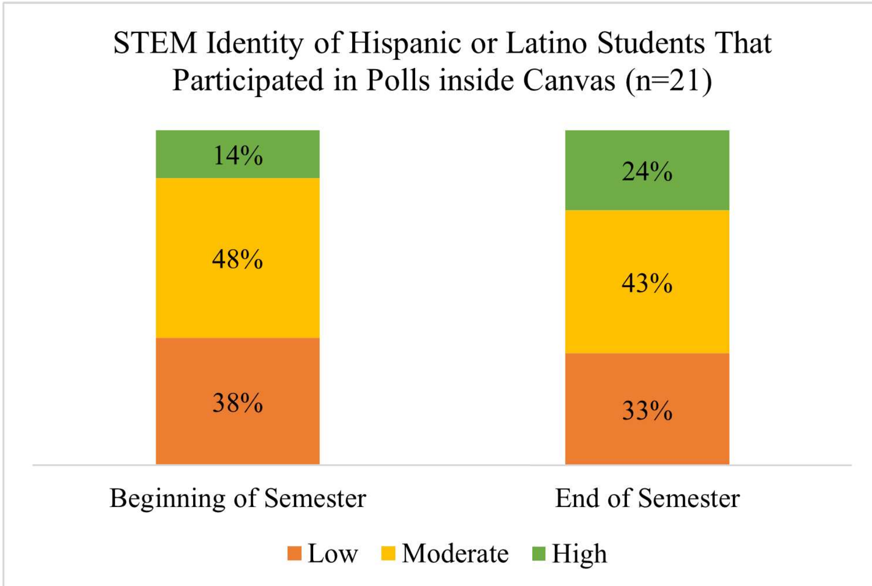

Figure 3-4 STEM Identity of Hispanic or Latino Students

During the fall semester of the 2023-24 school year, there were 34 Hispanic or Latino students enrolled in the STEM7 course. Of this group, there were 21 students in underrepresented groups that participated in the beginning of the semester poll and the end of the semester poll. There was an increase in the percentage of Hispanic or Latino students who completed the polls with a moderate to high STEM identity from the beginning of the semester (62%) to the end of the semester (67%). In addition, there were 11 Hispanic or Latino students who increased their self-ratings by any value from the beginning of the semester to the end.

3.1.1.4 Multi-Racial Students Subgroup

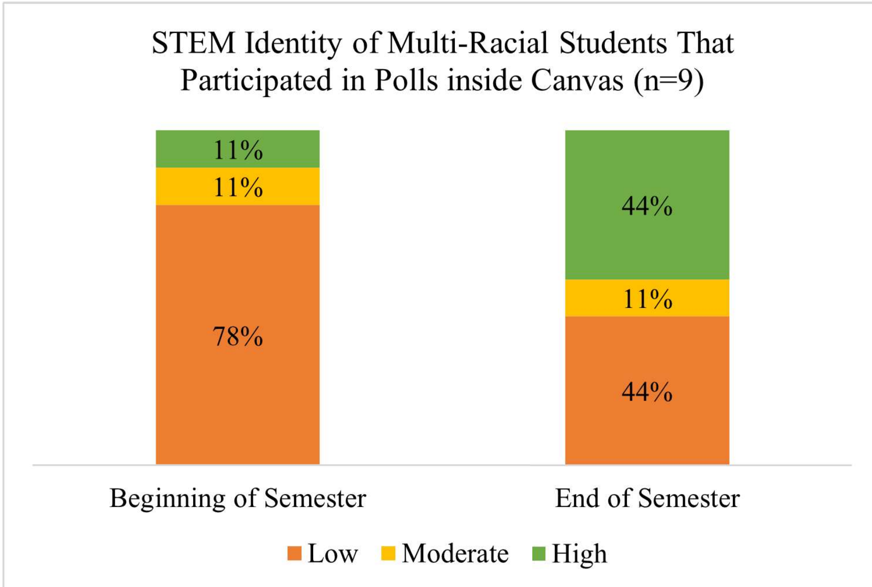

Figure 3-5 STEM Identity of Multi-Racial Students in STEM7 course

During the fall semester of the 2023-24 school year, there were 18 Multi-racial students enrolled in the STEM7 course. Of this group, there were 9 students in underrepresented groups that participated in the beginning of the semester poll and the end of the semester poll. There was an increase in the percentage of Multi-racial students who completed the polls with a moderate to high STEM identity from the beginning of the semester (22%) to the end of the semester (56%). In addition, there were four Multi-racial students that increased their self-ratings by any value from the beginning of the semester to the end.

3.1.1.5 Balancing Measure – White Students Subgroup

As a balancing measure, it was necessary to calculate the STEM identity of the remaining students (White subgroup) in the STEM7 course and compare the data. The interventions yielded an increase in the percentage of students who demonstrated a moderate to high STEM identity in both the underrepresented groups (Black or African American, Hispanic or Latino, Multi-racial) and the White subgroup. In the beginning of the semester, the percentage of White students in the STEM7 course who demonstrated moderate to high STEM identity was 59%, slightly higher than the percentage (55%) of students from underrepresented groups in STEM7. In the end of the semester, the percentage of White students that demonstrated moderate to high STEM identity was 62%, slightly lower than the percentage (65%) of students in underrepresented groups in the STEM7 course.

3.2 Poll Results from the STEM Role Models' Presentations

The data in this section was used to answer the inquiry question: In what ways did the presentations by the STEM role models affect the development of STEM identity in my students? In STEM7 Live Class sessions, presentations by STEM professionals were used to explore STEM careers. Polls were administered to all students before and after each presentation. In this section, only the poll data from students in underrepresented groups in the STEM7 Live Class sessions was used to answer the inquiry question.

Over the course of the four intervention cycles, there were a total of 55 students in underrepresented groups from the STEM7 course that attended the STEM professional presentations during Live Class sessions. Of those 55 students, there were 45 students that participated in a poll either before or after the presentation. This meant that 82% of the students in underrepresented groups that attended the STEM professional presentations participated in polls.

To measure the change for each intervention cycle, the STEM Professional Identity Overlap Measure was utilized. As mentioned previously, "it allows for repeated assessments that are not taxing for the individual being assessed, thereby providing a "snapshot" of the individual's identity at a particular moment, and enabling researchers and teachers to track how students' STEM identity evolves over time" (McDonald et al., 2019, p. 4). Two polls were administered using the STEM Professional Identity Overlap Measure. The Before poll was administered before the STEM professional's presentation during Live Class. The After poll was administered immediately after the presentation.

The following graphs were created with the same parameters used to measure the theory of improvement (see Section 3.1.1). In the graphs below, the x-axis represents the poll results from the before the presentation and after the presentation, where n = the number of students in underrepresented groups that participated in both polls.

3.2.1.1 Engineering Presentation – Poll Results

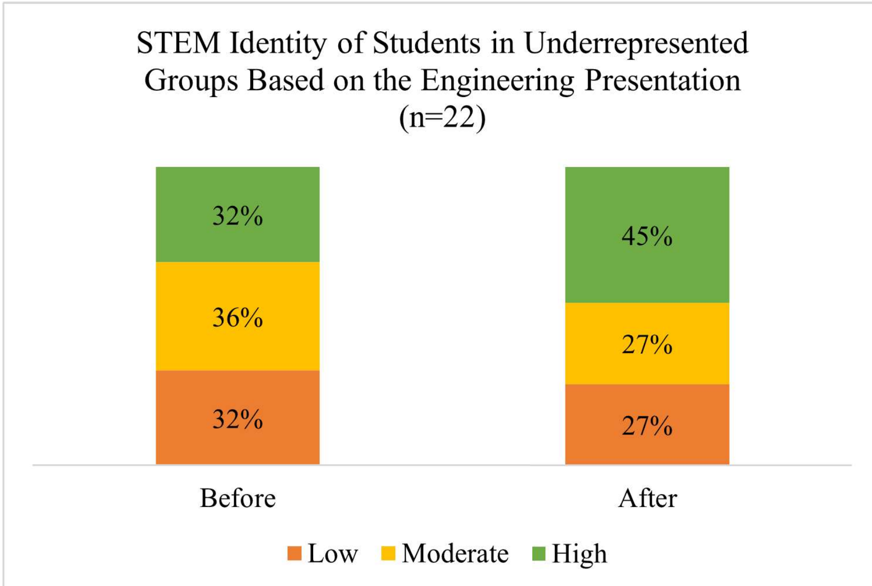

Figure 3-6 STEM Identity Based on the Engineering Presentation

The engineering STEM professional (a 24-year-old Multi-racial female) facilitated the first presentation of this study on September 28, 2023. There were 43 students in underrepresented groups in attendance. Of this group, there were 22 students in underrepresented groups that participated in the before the presentation and after the presentation poll. There was an increase in the percentage of students in underrepresented groups who completed the polls with a moderate to high STEM identity from before the presentation (68%) to after the presentation (72%). In addition, there were nine students who increased their self-ratings by any value from before the presentation to afterwards.

There was a statistically significant increase in the mean self-rating of the students in underrepresented groups from before the engineer's presentation to after the presentation. The t-Test: Paired Two Sample for Means was performed using this data. The results from the before the presentation poll ($M = 4.4$) and the after the presentation poll ($M = 5.0$) indicated that the intervention resulted in an improvement in STEM identity, $t(21) = -3.0$, $p = .004$ (one-tail), as measured by the STEM Professional Identity Overlap Measure. This analysis suggests that the intervention (utilizing diverse STEM role models to develop STEM identity) produced a notable change in the average self-rating among students and it was unlikely to have occurred by random chance.

3.2.1.2 Cyber Security Presentation – Poll Results

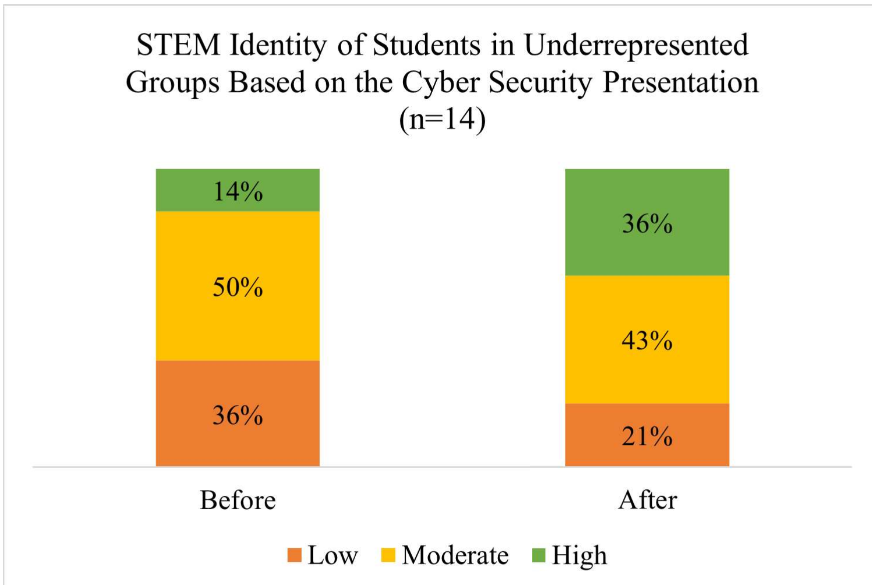

Figure 3-7 STEM Identity Based on the Cyber Security Presentation

The cyber security STEM professional (a 23-year-old Asian female) facilitated the second presentation of this study on October 26, 2023. Of this group, there were 14 students in underrepresented groups that participated in the before the presentation and after the presentation poll. There was an increase in the percentage of students in underrepresented groups who completed the polls with a moderate to high STEM identity from before the presentation (64%) to after the presentation (79%). In addition, there were six students who increased their self-ratings by any value from before the presentation to afterwards.

3.2.1.3 Forensic Science Presentation – Poll Results

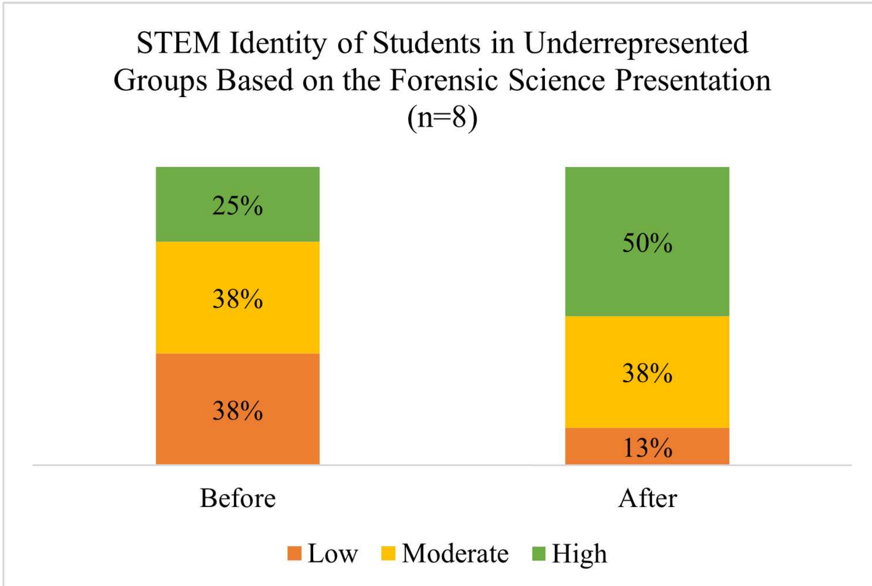

Figure 3-8 STEM Identity Based on the Forensic Science Presentation

The forensic science STEM professional (a 25-year-old Black female) facilitated the third presentation of this study on November 28, 2023. Of this group, there were eight students in underrepresented groups that participated in the before the presentation and after the presentation poll. There was an increase in the percentage of students in underrepresented groups who completed the polls moderate to high STEM identity from before the presentation (63%) to after the presentation (88%). In addition, there were five students who increased their self-ratings by any value from before the presentation to afterwards.

3.2.1.4 Finance Presentation – Poll Results

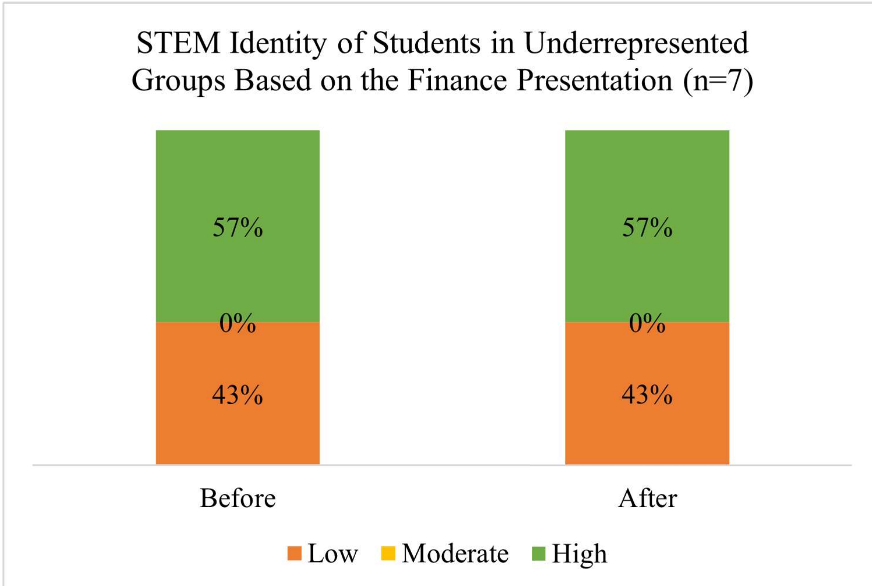

Figure 3-9 STEM Identity Based on the Finance Presentation

The financial STEM professional (a 35-year-old White female) facilitated the fourth presentation of this study on January 11, 2024. Of this group, there were seven students in underrepresented groups that participated in the before the presentation and after the presentation poll. There was no increase in the percentage of students in underrepresented groups who completed the polls moderate to high STEM identity from before the presentation (57%) to afterwards (57%). However, there were three students who increased their self-ratings by any value from before the presentation to afterwards.

3.2.1.5 Conclusion of Presentation Data

These findings suggested that a change occurred and students' STEM identity was developed as a result of the diverse STEM role models' presentations. During the first three intervention cycles, there was a consistent increase in the percentage of students in underrepresented groups who completed the polls with a moderate to high STEM identity from before the presentation to after the presentation. In addition, there were 23 instances of individual students in underrepresented groups who increased their self-ratings by any value from before the presentation to after the presentation.

There was a statistically significant increase in the mean self-rating of the students in underrepresented groups, specifically those who participated in the STEM professional presentations (as measured using the beginning of the semester poll to the end of the semester poll). The t-Test: Paired Two Sample for Means was performed using this data. The results from the beginning of the semester poll ($M = 3.6$) and the end of the semester poll ($M = 3.9$) indicated that the intervention resulted in an improvement in STEM identity, $t(36) = -1.7$, $p = .045$ (one-tail), as measured by the STEM Professional Identity Overlap Measure. This analysis suggests that the intervention (utilizing diverse STEM role models to develop STEM identity) produced a notable change in the average self-rating among students and it was unlikely to have occurred by random chance.

3.3 Student-Generated Questions Support STEM Identity

3.3.1 Content Analysis of Student-Generated Questions

The data in this section was analyzed using content analysis. The data was used to answer the inquiry question: How did student-generated questions support the development of STEM identity? In this study, students asked the STEM professionals their own questions. This approach allowed students to actively engage in the virtual classroom by taking ownership of their STEM learning process. Students observed the STEM professionals' presentations in anticipations of their questions being answered. In this section, question data from all students in the STEM7 course was used.

In this study, four STEM professionals facilitated presentations during Live Class sessions over the time period of September 2023 through January 2024. In total, students created 359 questions (see Appendix A) for the STEM professionals.

To begin the content analysis of the student-generated questions, I used a deductive approach to coding the question data because I noticed "strong connections to theoretical ideas, early on in the process" (Clarke & Braun, 2022, p. 57) and thus, coded around the concept of STEM identity. To guide this process, I used my inquiry question: How did student-generated questions support the development of STEM identity? I created a STEM identity framework (see Table 3) to code the questions that students created for the STEM professionals using the four components of STEM identity: interest, competence, self-recognition, and recognition by others. In creating this framework, I used the research from Sections 1.5.2 and 1.5.3 in the Review of Supporting Knowledge to define each component.

Table 3 STEM-Identity Framework

STEM Identity Component	STEM Identity Component Defined by Research
Interest	STEM instruction is perceived as useful by students or having a personal impact on them. (Brown et al., 2016)
Competence	Students feel confident in their STEM ability. (Brown et al., 2016)
Self-Recognition	Students envision themselves in a STEM career. (Kang et al., 2019) Students recognize potential in themselves. (Paul et al., 2020) Students have a sense of belonging in STEM fields. (Kim et al., 2018)
Recognition By Others	Students are recognized by others for their performance in STEM subjects. (Paul et al., 2020) Students feel like members of the social group of STEM professionals. (Kim et al., 2018)

Once the STEM identity framework was completed, I created four categories into which to sort the question data. I based these categories on the four components of STEM identity. A variety of questions fell into the Interest category, so it was necessary to divide this component into four subsections.

The category called Interest contained questions that indicated student interest in the STEM profession (subsection one). Examples of these questions included: “Do you have any tips for kids who want to be engineers?” and “What is it like to be a cyber security specialist?” Some questions indicated interest through personal details (subsection two). Examples of these questions included: “What college did you go to?” and “What were your hobbies as a kid?” Some questions indicated interest in the STEM career but with an element of worry (subsection three). Examples of these questions included: “Was it ever really difficult, where you needed help finding the evidence and taking pictures?” and “What do you do if you fail?” Some questions indicated favorable interest in general towards the job (subsection four). Examples of these questions included: “What was the best day on the job?” and “Do you enjoy it?”

The category called Competence contained questions that asked the STEM professional to clarify parts of the job or skills and abilities associated with the job. Examples of these questions included: “What was your very first engineering design?” and “What kind of security issues do you encounter most?”

The category called Self-Recognition contained questions in which students attempted to envision themselves in the STEM career being presented. These questions indicated the desire to possess a sense of belonging in the STEM profession, asking about the students’ own potential to succeed in the STEM field. Examples of these questions included: “If I were to do engineering, what would I do?” and “When did you know that your career path was the right one for you?”

The category called Recognition By Others contained questions in which students asked about the conditions and the treatment by others in STEM workplaces. These questions asked about colleagues in STEM fields and about the possibility of belonging in that social group of STEM professionals. Examples of these questions included: “Do you ever have any problems being a woman and a person of color in the engineering business?” and “What is it like being a woman in a male dominated industry?”

Students in the STEM7 course created questions about the STEM role models and the STEM professions represented in each intervention cycle. In the following graphs, the percentages of questions that fell into each of the four categories in the STEM identity framework are represented.

3.3.1.1 Engineering – Students' Question Types

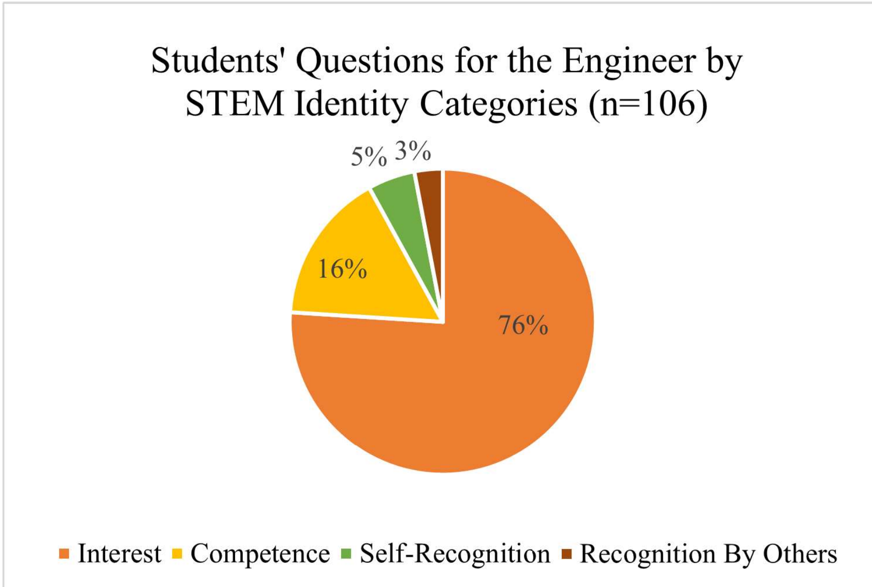

Figure 3-10 Students' Questions for the Engineer

During initial lessons on engineering, students in the STEM7 course created 106 questions for the engineer. The majority of the questions indicated interest in the engineer herself (43) or interest in the field of engineering (29). Several questions asked to clarify parts of the engineer's job or what indicated competence in her job (17). Some questions indicated interest in engineering but with an element of worry (9). A few questions touched on self-recognition (5) and the recognition by others (3) in the field of engineering.

3.3.1.2 Cyber Security – Students' Question Types

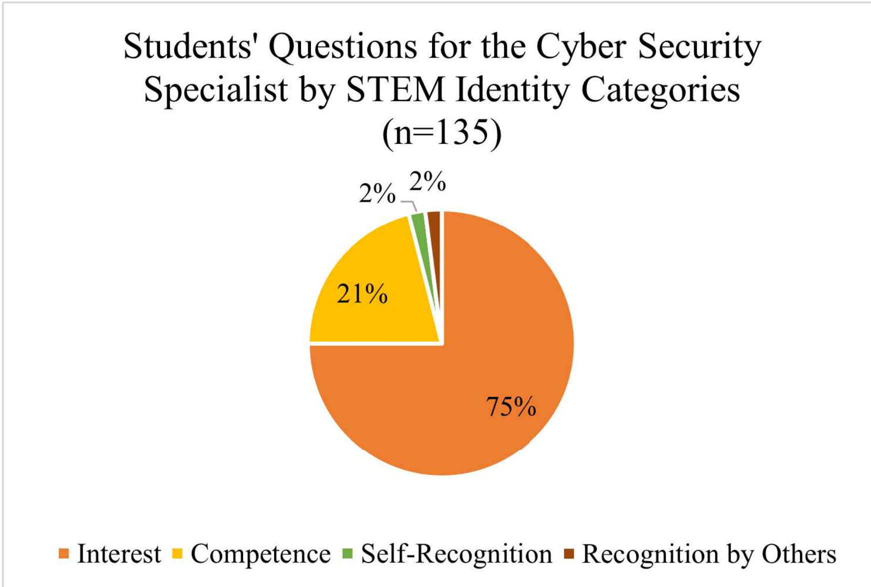

Figure 3-11 Students' Questions for the Cyber Security Specialist

During initial lessons on cyber security, students in the STEM7 course created 135 questions for the cyber security specialist. This was the highest number of questions created in any of the four intervention cycles. Similar to intervention cycle one, the majority of the questions were in the Interest category: interest in the field of cyber security (44) or interest in the cyber security specialist herself (43). Several questions asked the cyber security specialist to clarify parts of her job or what indicated competence in her job (29). Some questions indicated interest in cyber security but with an element of worry (13). There were a few questions that explored self-recognition (3) and recognition by others (3) in the field of cyber security.

Overall, there were more total questions generated for the STEM professional in intervention two than intervention one. The greatest increase in question type was in the Competence category. Students generated more questions that asked the cyber security specialist specific questions about her job than the engineer.

3.3.1.3 Forensic Science – Students' Question Types

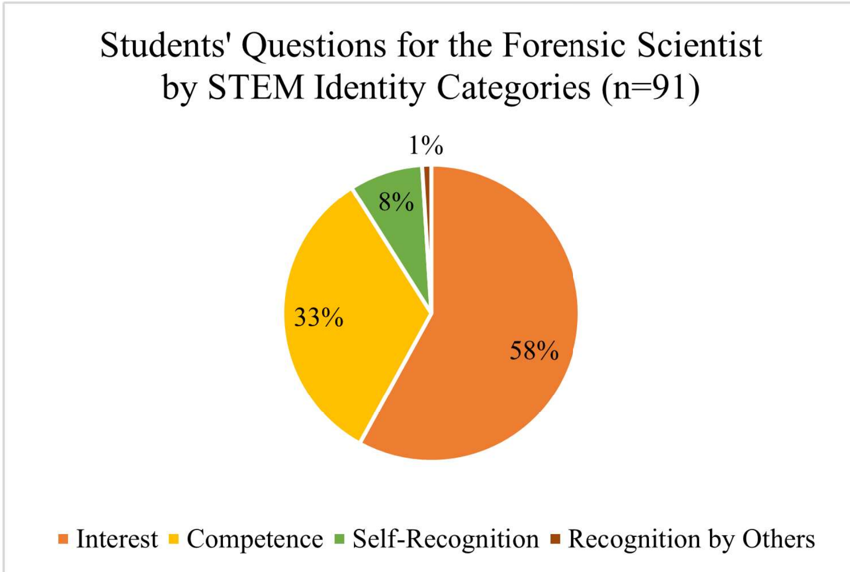

Figure 3-12 Students' Questions for the Forensic Scientist

During initial lessons on forensic science, students in the STEM7 course created at least 91 questions for the forensic scientist. (The actual number of student-generated questions was greater than this but one class set of question data was lost due to an accidental file overwrite). This was the first intervention in which the majority of the questions asked the STEM professional what indicated competence in her job or to clarify parts of her job (30). Some questions indicated interest in the field of forensic science (30) or interest in the forensic scientist herself (16). A few questions indicated interest in forensic science but with an element of worry (7). There were more questions that reflected on self-recognition (7) than recognition by others (1) in the field of forensic science.

Overall, there was an increase in the number of Competence and Self-Recognition questions in intervention three compared to intervention two. This occurred despite the fact that only three of the four classes' questions were collected.

3.3.1.4 Finance – Students' Question Type

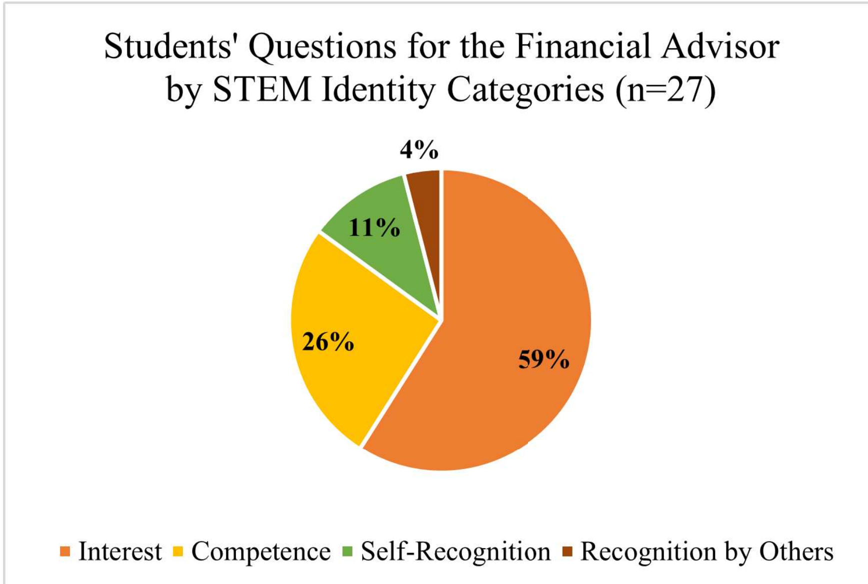

Figure 3-13 Students' Questions for the Financial Advisor

During initial lessons on finance, students in the STEM7 course created only 27 questions for the financial advisor. A probable cause for this was timing. The initial lessons occurred on the first two days after a holiday break and Live Class attendance was unusually low. Consistent with the other interventions, the majority of the questions indicated interest in the financial advisor herself (7) or interest in the field of finance (6). Some questions asked her to clarify parts of her job (7). Only a few questions indicated interest with an element of worry (3). There were some questions that asked about self-recognition (3) and recognition by others (1) in the field of finance.

3.3.1.5 Conclusion of Student-Generated Question Data

These findings suggest that student-generated questions supported the development of STEM identity. The questions were used by the STEM professionals to bring a deeper understanding of the STEM fields to the students.

As demonstrated in Table 4, students in the STEM7 course created questions for the STEM professionals that fell into all four categories of the STEM identity framework. The majority of the questions fell into the Interest and Competence categories. Nearly a third of the students' questions (30%) indicated interest in the STEM professionals. Additionally, students created questions that indicated interest in the STEM professions (24%) and asked the STEM professionals to clarify parts of the job or skills needed to perform the job (23%). The fewest questions were created in the Self-Recognition and Recognition by Others categories.

Table 4 Categories of STEM Identity Questions by Students

Categories of STEM Identity	Engineering	Cyber Security	Forensic Science	Finance	Total
Interest in the person	43	43	16	7	109
Interest in the job	17	36	28	6	87
Interest general/favorable	12	8	2	0	22
Interest with some worry	9	13	7	3	32
Competence	17	29	30	7	83
Self-Recognition	5	3	7	3	18
Recognition by Others	3	3	1	1	8
Total	106	135	91	27	359

Over the period of three intervention cycles, there were noticeable changes in the amounts of questions in two of the categories (the sample size was too small for the fourth intervention to be included). As demonstrated in Figure 3-14, the number of questions in the Competence category increased over the first three intervention cycles (from 17 to 30). This could explain the reason for the decrease in interest general/favorable questions (from 12 to 2) over the same intervention cycles. For example, the questions seemed to evolve from general interest ("What is the best part of the job?") to job-specific questions ("What if the victim doesn't give you enough information?").

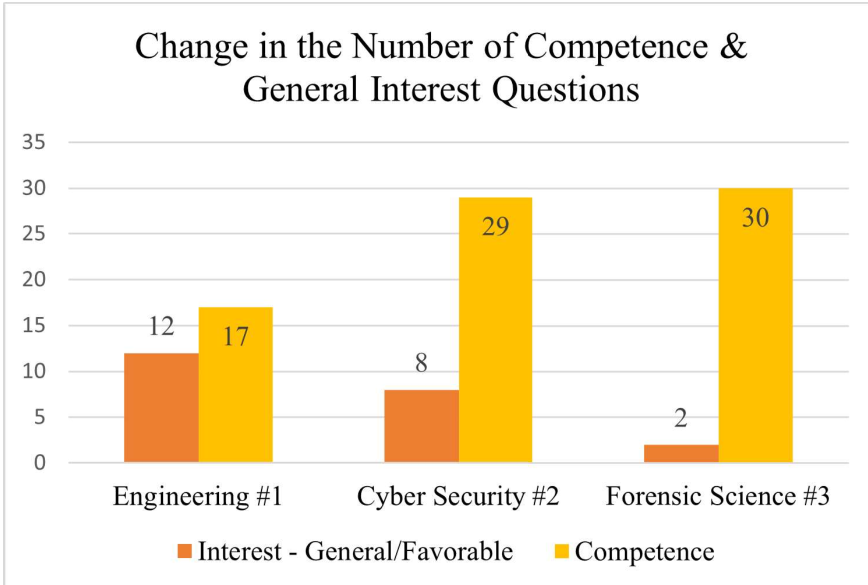

Figure 3-14 Change in the Number of Competence and General Interest Questions

Although the number of Self-Recognition questions never equaled the number of questions in the other categories, the number of Self-Recognition questions did increase over the intervention cycles.

3.3.1 Thematic Analysis of Student-Generated Questions

After the student-generated questions were coded using content analysis, I took a second approach to the data. I used thematic analysis to identify patterns and find common themes. I examined the data with the inquiry question in mind: How did student-generated questions support STEM identity development? I observed the progression of students' questions as they evolved through five discernible stages.

Stage 1: Connections Made

There were questions in which students appeared to be determining if the STEM professionals were similar to themselves. These questions attempted to make connections between the students and the STEM professionals using familiar concepts like favorite books, hobbies, toys, and subjects in school. Additionally, students tried connecting with the STEM professionals about family, parents, siblings, and pets. One student asked the engineer for ideas about the student's homework assignment, which was a design challenge. For the most part, students wanted to find common ground between themselves and STEM professionals.

Stage 2: Trust Established

After students had found some common ground with the STEM professionals, their questions shifted to speculating about the possibility of having similar careers themselves one day. The students seemed to determine that the STEM professionals were like themselves and could be trusted with their next level of questioning. These questions were exploratory: “What's it like?” “How did you get into it?” “Did you always know this was the job for you?” “What age did you know?” “Were there other careers you thought about?” The students appeared to be envisioning themselves in similar careers to the STEM professionals.

Stage 3: Surface Level Interest

After the students established trust with the STEM professionals and appeared to feel safe asking the STEM professionals questions, the questions moved in a direction somewhat resembling common interview questions. These questions were practical and seemed to center around surface details of the jobs: salary, length of career, travel opportunities, schedule of the day, and position in the company. Some surface level questions were more personal. For example, one student questioned the engineer “How does engineering improve your life?”

Stage 4: Deeper Level Interest

After the students established interest in the STEM professions by asking surface level questions, they asked technical questions about the STEM professions. Their knowledge was limited due to their age, but they attempted to use technical terms (i.e. reference charts, cyber threats, UV scales, certification process) that they learned in the STEM7 course or through self-study. Their questions seemed to indicate a more detailed understanding of the various STEM fields. For example, one student asked the cyber security specialist “Do you help people recover from internet Wi-Fi attacks such as direct denial of service attacks?”

Stage 5: Worry Persisted

Even though trust was established, connections were made, and interest was piqued in the STEM professions, an element of worry lingered in some questions. These questions implied students fears, specifically by using terms like hard, challenge, stressful, angry, fail, proper treatment, and help. By the end of the intervention cycles, the percentage of questions with an element of worry diminished. However, these types of questions were present in every intervention cycle, which could indicate a persistent challenge in developing STEM identity.

In summary, the five stages of student-generated questions began with questions that made connections. After connections were made, the students appeared to determine that the STEM professionals were like themselves and could be trusted with their next level of questioning. Questions then transitioned from surface-level interests to a deeper understanding of the STEM fields and professionals. Despite students’ growing interest, some worry lingered in the students’ questions, reflecting concern about the consequences of failing at the job.

3.4 Evidence of STEM Identity in Survey Responses

The data in this section will be used to answer the inquiry question: What evidence was there of STEM identity development in my students’ survey responses? After the presentations by the STEM professionals had concluded, all students in the STEM7 course had the opportunity to reflect on their STEM learning. In this section, survey data from all students in the STEM7 course was used.

For each intervention, STEM7 students responded to a survey titled "STEM Profession Assignment" after each STEM professional's presentation in Live Class. This survey, along with a recording of the STEM professional's presentation, was posted as an assignment in Canvas for all STEM7 students to complete. In total, the survey was administered four times throughout this study. The survey consisted of four Likert-scale statements and three open-response questions and the data was gathered electronically in Canvas.

3.4.1 Survey Statement Data

During this study, there were 468 surveys submitted asynchronously in Canvas. From these surveys, there were 1,871 responses to the four statements. The following table (Table 5) contains data from all students in the STEM7 course.

Table 5 STEM Identity Survey – Statement Data

STEM Profession	Surveys Submitted	Statement Responses
Engineering	164	656
Cyber Security	153	612
Forensic Science	129	515
Finance	22	88

Using this data, I created frequency distribution tables and calculated the mode and mean for each survey statement in each of the four intervention cycles.

3.4.1.1 Interest – Survey Statement Data

Table 6 Interest Survey Statement Data

STEM Profession	Mode	Mean
Engineering	3.0	3.09
Cyber Security	2.0	2.56
Forensic Science	3.0	2.74
Finance	1.0	2.04

The survey statement “On a scale of 1 to 5 (where 1 is not very much and 5 is very much) how interested are you in careers that use (insert STEM profession)?” measured students’ interest in STEM professions. The survey statement data in Table 6 suggested that students were most interested in engineering and the least interested in finance.

3.4.1.2 Competence – Survey Statement Data

Table 7 Competence Survey Statement Data

STEM Profession	Mode	Mean
Engineering	3.0	3.25
Cyber Security	3.0	2.97
Forensic Science	3.0	2.91
Finance	3.0	2.87

The survey statement “On a scale of 1 to 5 (where 1 is the least and 5 is the most), answer this: I am able to do well in activities that involve (insert STEM profession).” measured students’ competence in activities related to various STEM professions. In Table 7, the survey statement data suggested that students felt more competent in their ability to complete engineering activities than any of the other STEM fields.

3.4.1.3 Self-Recognition – Survey Statement Data

Table 8 Self-Recognition Survey Statement Data

STEM Profession	Mode	Mean
Engineering	3.0	2.98
Cyber Security	1.0	2.48
Forensic Science	1.0	2.19
Finance	3.0	2.39

The survey statement "On a scale of 1 to 5 (where 1 is the least likely and 5 is the most likely), how likely are you to use (insert STEM profession) in your future career?" measured students' ability to envision themselves in various STEM professions. The survey statement data in Table 8 suggested that students were more likely to envision themselves in careers involving engineering than any of the other STEM fields.

3.4.1.4 Recognition By Others – Survey Statement Data

Table 9 Recognition By Others Survey Statement Data

STEM Profession	Mode	Mean
Engineering	4.0	3.4
Cyber Security	4.0	3.36
Forensic Science	3.0	3.3
Finance	3.0	3.13

The survey statement "On a scale of 1 to 5 (where 1 is the least and 5 is the most), answer this: I would feel comfortable talking to people who work in (insert STEM profession)." measured students' sense of belonging in the social groups of various STEM professionals. The survey statement data in Table 9 suggested that students felt a similar sense of belonging among STEM professionals in engineering, cyber security, and forensic science.

3.4.1.5 Conclusion of Survey Statement Data

Overall, the analysis of the survey statement data reflected a consistent presence of engineering in the STEM identity of the students in STEM7 course. The data suggested that students were most interested in engineering and felt the most competent in engineering activities over the other STEM professions. Students were most likely to envision themselves as engineers and felt the greatest sense of belonging among others in the field of engineering.

3.4.2 Survey Response Data

After each STEM professional's presentation, students had the opportunity to reflect on their STEM learning through the survey. I used students' reflections on STEM learning (as demonstrated in the survey responses) as evidence for STEM identity development. During the study, there were 468 surveys submitted asynchronously in Canvas (see Table 10). From these assignments, there were 1,224 responses to the three open-response questions collected using the STEM identity survey. All STEM7 students' responses were included in this data.

Table 10 STEM Identity Survey – Open-Response Question Data

STEM Profession	Surveys Submitted	Question Responses
Engineering	148	656
Cyber Security	132	612
Forensic Science	122	515
Finance	22	92

3.4.2.1 Engineering – Survey Response Summary

In this section, I summarized the responses to the three open-ended questions pertaining to engineering. After the engineering presentation, data was electronically collected for 26 days. In total, there were 148 surveys submitted that yielded usable open-response question data (444 responses) submitted in Canvas.

In the first question, students responded to the prompt: “What is one new thing you learned about the engineer (Mary)?” Many students were able to recall information that Mary shared about her education, hobbies, family, and favorite subject (math). Students also recalled that Mary liked to take apart her toys when she was young and played with LEGOs (which she still does). Interestingly, students recalled that Mary wanted to be an engineer from a young age.

In the second question, students responded to the prompt: “Which part of the engineer's (Mary's) job did you like the best? Why?” Some students liked the opportunities that Mary had to travel and learn new things. Other students liked the creativity and inventing aspect of engineering and similarly, problem solving and the improvement process. A handful of students liked that engineering uses math, art, and science. Finally, many students liked that Mary’s job allowed her to help other people, including managing others and being part of a team.

In the third and final question of the assignment, students responded to the prompt: “What was the most important new thing you learned about engineering from Mary’s presentation?” Some students mentioned that engineering sounded like fun while nearly twice as many students mentioned that it sounded challenging or hard. Some students echoed Mary’s engineering logic that mistakes are good to make. Several students mentioned skills relevant to engineering, such as collaboration and teamwork, building and improving things, being knowledgeable, and coming up with new ideas. Other students learned that being a leader and respectful to others were parts of engineering. Finally, students learned about the different types of engineering from Mary’s presentation.

3.4.2.2 Cyber Security – Survey Response Summary

In this section, I summarized the responses to the three open-ended questions pertaining to cyber security. After the cyber security presentation, data was electronically collected for 26 days. In total, there were 132 surveys submitted that yielded usable open-response question data (393 responses) submitted in Canvas.

In the first question, students responded to the prompt: “What is one new thing you learned about Heather, the cyber security specialist?” Students recalled learning about Heather’s family and interests, like exploring Washington D.C. and cooking. They learned about her college experience (running track) and military training (being pepper sprayed, in particular). Some students mentioned that she became interested in cyber security after taking a coding class in college, and that there are few women in her profession. Students learned that Heather’s goal is to help others and that she wants to be a cyber lawyer someday.

In the second question, students responded to the prompt: “Which part of the cyber security specialist’s (Heather’s) job did you like the best? Why?” Many students responded about Heather’s ability to help people and save lives through her job. Students talked about her experiences living on a ship. Many students were able to recall skills that Heather uses in her job, like hacking into computers and networks, preventing hackers, creating passcodes, and keeping others safe from online threats. Students mentioned learning about Heather’s training and the importance of teamwork in her job.

In the third and final question of the assignment, students responded to the prompt: “What was the most important new thing you learned about cyber security from Heather’s presentation?” Many students mentioned specific parts of the cyber security job, such as monitoring networks, responding to cyber-attacks, and identifying scams in emails. Several students recognized the importance of cyber security for protecting people's data and helping others by "watching everything 24/7." Students indicated that cyber security is a big responsibility and that there is training required for it.

3.4.2.3 Forensic Science – Survey Response Summary

In this section, I summarized the responses to the three open-ended questions pertaining to forensic science. After the forensic science presentation, data was electronically collected for 14 days. In total, there were 122 surveys submitted that yielded usable open-response question data (365 responses) submitted in Canvas.

In the first question, students responded to the prompt: "What is one new thing you learned about Abigail, the forensic scientist?" Many students were able to recall information that Abigail shared about her job, such as training and certifications, the fingerprinting process, tools and strategies she uses to collect and preserve evidence (bullets, TPPO, works in damaged conditions), working with others (including detectives and a dog), and testifying in court. Students also recalled that Abigail uses various skills in her job, such as self-learning and patience; she "takes her job seriously," "asks for help," and "is mentally strong." Interestingly, students recalled that Abigail learned about forensic science when she was "about our age [12-13]."

In the second question, students responded to the prompt: "Which part of the forensic scientist's (Abigail's) job did you like the best? Why?" Some students liked the process of handling, collecting, gathering, and preserving evidence at crime scenes. They liked the equipment and tools used to document what happened (such as taking pictures and finding fingerprints and clues) and test the evidence (such as chemicals, powders, and the lab). Other students liked the part of Abigail's job where she testifies in court and helps police to solve crimes. Students also liked the teamwork aspect of the job and the fact that she works with multiple departments and doesn't get bored with her job. A handful of students liked that Abigail uses math, science, and physics in her job. Finally, other students liked that her job allowed her to help the community and work with dogs.

In the third and final question of the assignment, students responded to the prompt: "What was the most important new thing you learned about forensic science from Abigail's presentation?" Many students mentioned that forensic science is an important job that is serious and thorough. One student wrote, "there's more than meets the eye" because a lot "goes into the job." Students shared that Abigail's job can be very tricky with lots of work to complete. Several students mentioned the importance of asking for help or asking questions in the forensic scientist's job. To some students, digital forensic science was a new concept to them.

3.4.2.4 Finance – Survey Response Summary

In this section, I summarized the responses to the three open-ended questions pertaining to finance. After the finance presentation, data was electronically collected for seven days. In total, there were 22 surveys submitted that yielded usable open-response question data (66 responses) submitted asynchronously through a Google form. Due to the approaching end of the semester, the submission method was changed to encourage more students to complete the survey.

In the first question, students responded to the prompt: "What is one new thing you learned about Andrea, the financial advisor?" Students recalled that Andrea liked to help her clients and people of all generations. They mentioned the skills that Andrea discussed, specifically the importance of people skills and being prepared for problems that arise. One student commented, "She likes her job because she sees people change in a good way and it makes her happy to see other people happy." Some students remembered that Andrea learned a lot of math in college.

In the second question, students responded to the prompt: "Which part of the financial advisor's (Andrea's) job did you like the best? Why?" Students' responses seemed to indicate that they liked the variety of responsibilities within the financial advisor's job. They recalled that there was "no typical day" in finance for Andrea and that "keeps the job different and interesting." Students liked the life-changing advice that financial advisors offer their clients in banking and tracking finances. One student responded, "(I like) how confident she is being a woman in the financial business." Students clearly remembered how Andrea thought her job was rewarding.

In the third and final question of the assignment, students responded to the prompt: "What was the most important new thing you learned about finance from Andrea's presentation?" Some students' responses focused on the technical components of financial advising, like stock trading, updating retirement plans, and passing exams to gain licenses. Other students' responses explained the people skills required in Andrea's job, like gaining the trust of clients, being patient, and the ability to work with all kinds of people. One student recalled the investment activity that Andrea led during her presentation. The activity demonstrated the growth of investments over time using an Excel spreadsheet. The student remembered, "It takes a whole lifetime to save money and for it to grow."

3.4.2.5 Conclusion of Survey Responses

Overall, the analysis of the open-response question data from the four intervention cycles provided evidence of STEM identity development in the students in the STEM7 course. The vast majority of students expressed interest in the STEM professions. Most of the students were able to articulate information specific to competence in each of the four STEM professions in this study. Many students were able to make personal connections to the STEM professionals and envision themselves in the STEM fields. It appeared that some students felt like they could belong with other professionals in the STEM fields sometime in the future.

3.4.2.6 Student Example of STEM Identity Development

To conclude this section, I chose responses from a single student (whose name was changed for confidentiality) to demonstrate evidence of STEM identity development over the course of the four PDSA cycles. This student took full advantage of the interventions by regularly attending and participating in the initial lessons and the STEM professionals' presentations. This student completed all of the polls and the four surveys in a timely fashion. This student was unique among her STEM7 classmates with this level of participation.

During the time of this study, Lauryn was a 12-year-old, Multi-racial female in STEM7 class. In the beginning of the semester, she self-identified as having a moderate to high (5,6) level of STEM identity (according to the STEM Professional Identity Overlap measure), but she didn't offer any personal stories or explanation for the rating.

During the first intervention, Lauryn created two questions for the engineer, including "What made you want to be an engineer?" In posing this question, Lauryn was looking for ways to recognize in herself the desire to be an engineer (Self-Recognition in STEM identity). After Lauryn attended the engineer's presentation, the answers to her survey questions suggested the development of STEM identity. In response to the question "Which part of the job did you like best? Why?" Lauryn indicated interest in the engineering company's motto: to make a better and more efficient world that works. She liked this motto because it indicated the company's care about others and being a "reliable and sustainable workplace." She admired the engineer's love for the job. These responses provided evidence that the presentation by the engineer nurtured Lauryn's

STEM identity. Lauryn was able to identify aspects of the engineering profession that she could connect with – improving the world, caring about others, and having reliable work.

During the second intervention, Lauryn created 11 questions for the cyber security specialist. One of her questions asked about the cyber security specialist's hobbies. In an answer to a survey question, Lauryn indicated that she "learned that [Heather] loved volleyball and did not just work in cyber activities." Lauryn appeared to be making connections between the STEM role model and herself based on common interests. Another question by Lauryn asked, "Was this the dream job [for you]?" After the presentation, Lauryn responded "[Heather] says she wants to become a cyber lawyer and I didn't even know that could be a job in the cyber world" to a survey question. She noted in her response that "cyber security is in every branch of the [military]." These responses provided evidence that the specialist's presentation sparked an interest in this STEM profession for Lauryn.

During the third intervention, Lauryn created eight questions for the forensic scientist. Some of her questions asked about specific skills in the STEM profession. She asked, "Do you have to learn more about photography because of your job?" After the presentation, Lauryn responded, "[Abigail] is not just looking at dead bodies, but analyzing the crime scene, and studying photography which I think is very cool" to a survey question. Another question posed by Lauryn asked, "What did you have to do to get your job today?" In a survey question response, she indicated that there were many components to the forensic scientist's job. "I had no clue there was [such] a thing as digital forensic science, but that is a factor to her job that I did not know." These responses provided evidence that the STEM role model's performance of various job duties was interesting to Lauryn. She was curious about the STEM role model's performance or competence in the role of forensic scientist.

Prior to the final intervention, Lauryn did not create questions for the financial advisor due to an absence after a holiday break. However, Lauryn did attend the financial advisor's presentation during Live Class session. The responses to her survey questions provided evidence of STEM identity. She indicated an understanding of the job responsibilities of a financial advisor, such as "helps people and communicates with clients" and "building a bond with a client and gaining their trust that you will help them out." Lauryn expressed interest in the performance of the STEM role model's job responsibilities which suggested the development of STEM identity.

Near the end of the semester, Lauryn self-identified as having a high level (6,7) of STEM identity and this time, she offered an explanation. "To me, STEAM means you being your most intuitive creative self. What I've learned this semester is that STEM/STEAM can be anything YOU want it to be. Of course, we have the dictionary definition of STEM, but to me I can find stem in anything, and I think that what's so amazing about STEM. STEM/STEAM is very important and to some it can be an outlet of the creative mind and can show your ingenuity. So, this is why I believe a STEM-self is your best-self."

Lauryn's participation in this study was exemplary. Her survey responses suggested that her STEM identity had been nurtured throughout the four intervention cycles. Her responses also suggested that she felt respected in the virtual classroom when her questions were answered by the presenters. She engaged with the STEM professionals, several of whom were female like her and looked like her, during presentations in Live Class sessions. As a result of this experience, her responses suggested that Lauryn developed a sense of belonging in the virtual classroom and a sense of belonging in various STEM fields.

3.5 Results of Intervention Strategies

As I designed instruction for my STEM7 course, I searched for ways to nurture STEM identity in students learning in the virtual classroom. I chose improvement science to support this ambition. Brandi Nicole Hinnant-Crawford explains, “the PDSA [is] a cycle for both learning and improvement. It is designed to build new knowledge with each additional cycle – about what works, what does not work, for whom, and under what conditions" (2020, p. 160). The PDSA cycles of this intervention provided me with knowledge to improve my classroom instruction and supported the development of STEM identity in my students, despite the barriers of online learning.

The first intervention cycle was facilitated in September 2023. The intervention occurred during STEM7 Live Class sessions in lessons that explored STEM careers. The change idea being tested was to utilize diverse STEM professionals (that reflected students’ cultural identities) to increase students’ STEM identity. This idea was influenced by the research of Steinke et al in “Effects of Diverse STEM Role Model Videos in Promoting Adolescent’s Identification” (Steinke et al., 2022). The intervention was completed (see Appendix B). It resulted in the predicted outcome, suggesting that students’ STEM identity was developed as a result of the diverse STEM role models’ presentations.

However, something unexpected (though exciting to see) happened during the intervention. After the engineer facilitated her presentation, several female students engaged with the engineer for an additional 30 minutes during Live Class. While the students were engaging with the engineer, I observed that the questions these girls asked the engineer after the presentation. The questions were worded much more clearly than the incomplete and fragmented questions that were submitted before the presentation. Based on this observation, I wondered if support in questioning strategies might help students form better questions for the next presentation.

In response to this hypothesis, I researched Norman Webb's Depth-of-Knowledge (DOK) framework (Webb, 2002) to engage students in the process of writing questions. This was the basis for the next change idea. I adapted instruction in Live Class sessions to teach students how to write questions at all four levels. Afterwards, the questions were emailed to the cyber security specialist to answer in her presentation during Live Class. In order to evaluate the complexity of the students' questions, I utilized a version of the DOK framework to create a matrix to categorize the questions (see Table 11). "Webb's DOK is very robust, and this approach to thinking about classifying items and standards by cognitive complexity is merely a lateral extension of it" (Wine & Hoffman, 2022, p. 4).

Table 11 Norman Webb's Depth of Knowledge Framework

DOK Level	Keywords	Description
Level 1: Recall & Reproduction	Identify, Recall, Define, Restate	Fact-based questions, single correct answer; very little cognitive processing and interpretation of the information.
Level 2: Application of Skills & Concepts	Classify, Organize, Estimate, Create, Explain	Make informed decisions; describe cause/effect; connect ideas.
Level 3: Short Term Strategic Thinking	Justify, Explain, Draw Conclusions	Support ideas with details and examples; reasoning and planning; explain thinking when more than one response is possible
Level 4: Extended Strategic Thinking	Relate, Make Connections, Analyze, Reflect	Complex reasoning, developing over time; evaluate, provide justification

The second intervention cycle was facilitated in October 2023. The change idea was to increase students' knowledge of effective questioning strategies. To do this, I taught students about the four levels of questions using the DOK framework. I predicted that students would create more questions as a result of this change idea. The goal of this test of change was to increase opportunities for students to develop their STEM identity based on the students' improved questions. The intervention was completed (see Appendix C) and resulted in the predicted outcome. The students in Live Class created more questions for the cyber security specialist's presentation that they did for the previous intervention.

STEM7 students created 139 questions for the cyber security specialist with all four levels of complexity represented. The majority of the questions (58%) were level one questions that asked basic recall questions or asked the guest speaker to identify something. However, over a quarter of the questions (27%) were level 2 questions that asked the guest speaker to make informed decisions on topics or to classify/organize information. Some of them (11%) were level 3 questions that asked her to justify or explain information. A small percentage of the questions (4%) were level 4 questions that required complex reasoning. After learning about Webb's four levels of questions, students created complex questions for the cyber security specialist. The total number of submitted questions increased by 33 from the first intervention to the second intervention.

The third intervention cycle was facilitated in November 2023. The change idea was to practice questioning strategies in various lessons within the STEM7 curriculum. To do this, I integrated instruction on questioning strategies with a game design project. This lesson was a week before the lesson in which students created questions for the forensic scientist. The predictions and goals of the test of change were the same as intervention two. The intervention was completed (see Appendix D) and resulted in the predicted outcomes (based on percentages). The students in Live Class created more complex questions for the forensic scientist's presentation.

STEM7 students created (at least) 91 questions for the forensic scientist with all four levels of complexity represented (some of the students' questions were lost due to a file error). The majority of the students' questions (53%) were level one questions. However, there was an increase in level three questions (up to 24% from 11%) from the previous intervention cycle, suggesting that, as a result of this intervention, students created more complex questions for the forensic scientist in intervention three than for the cyber security specialist in intervention two.

The strategies in the interventions contributed to the development of STEM identity in my students. By teaching the students to create more complex questions, students were able to gain more information from the STEM professional presentations.

4.0 Learning

4.1 Discussion

The results of this study suggest that the interventions nurtured positive STEM identities in students, particularly students in underrepresented groups in the STEM7 course at Reach Cyber. These interventions were designed to be valuable learning experiences that combined teaching about diversity and inclusion with exposure to diverse STEM role models. The intention was for middle school students in underrepresented groups to feel a sense of belonging in various STEM fields and in the virtual classroom. The use of diverse STEM role models appeared to make students feel valued and accepted in the virtual classroom community and invested in learning about STEM careers.

4.1.1 Sense of Belonging is Important to Developing STEM Identity

The key finding of this study was that students in underrepresented groups increased their STEM identity rating through their STEM7 coursework and that the increase was not the result of random chance (see Sections 3.1.1.1 and 3.2.1.5). Throughout this study, students in underrepresented groups were motivated to engage in both Live Class sessions and asynchronous coursework. Teacher characteristics, such as a caring and understanding, could have encouraged this level of engagement. Lee et al. (2022) found that there are teacher characteristics that encourage students' interest in STEM. "Aside from demonstrating interest in the subject, teachers who demonstrated that they were passionate about students' academic development were also identified by the participants [students] as encouraging" (Lee et al., 2022, p. 18). I demonstrated passion for my students' STEM success by reading students' names and questions aloud in Live Class sessions while students' generated questions for the STEM professional presentations. This student recognition activity most likely made students feel like valuable members of the classroom community when their accomplishments were recognized. The recognition encouraged engagement in the virtual classroom. I demonstrated interest in STEM learning by arranging for diverse STEM role models to present to my students and talk about the realities of being a member of a minority group in a STEM profession. This action most likely made students in underrepresented groups more invested in learning about STEM careers while also learning about diversity and inclusion. Similar to Singer, Montgomery, & Schmoll's (2020) findings, I found that these three factors (authentic learning experiences, teaching about diversity, and instilling a sense of belonging) were important contributors to developing and nurturing STEM identity formation in students.

As predicted by the driver diagram (see Figure 2-1), one of the main findings of this research study was that using asynchronous coursework to teach students about STEM careers appeared to nurture STEM identity in STEM7 students. In "Exploring the Concerns of Online K-12 Teachers," Farmer and West's (2019) teacher interviews found that communication with students and parents is problematic in virtual schools. For the majority of STEM7 students, the only communication between myself and my students was through Canvas. By embedding STEM identity activities into the STEM7 curriculum and requiring them to be completed in Canvas as part of the students' grades, I communicated the importance of these STEM learning activities and STEM identity in the syllabus of the STEM7 course. This purposeful integration may have contributed to the students' level of engagement with the asynchronous coursework that led to their STEM identity development throughout the STEM7 course.

4.1.2 Female STEM Role Models Affect STEM Identity

In this section, I examine findings from the STEM role models' presentations. The findings suggest that students in underrepresented groups (particularly female students) found a sense of belonging in STEM fields and in the virtual classroom as a result of the interventions.

An unexpected finding in this research study was that a vast majority of the students (16 out of 20) who stayed after class and asked questions after the STEM professional presentations were female students. It's possible that using ethnically diverse and female STEM role models in the virtual classroom developed a sense of belonging in my female students. Bringing these female groups together (students and STEM professionals) may have supported the students' desire to learn about STEM careers and instilled a sense of belonging in the STEM fields. In their study, Xu and Lastrapes found that a sense of belonging impacted female students' attitudes related to STEM careers. "Based on our analysis of the female sample, STEM attitudes may be targeted as a specific point for education interventions because STEM sense of belonging appears to indirectly impact career interest" (Xu & Lastrapes, 2022, p. 1225). The educational intervention (question and answer format between the students and STEM professionals) may have helped the female students in underrepresented groups to feel a sense of belonging in the various STEM fields (engineering, cyber security, and forensic science) discussed during the presentations.

An important finding from this study was that after every presentation with a Multi-racial, Black, or Asian speaker, students showed an increase in STEM identity self-ratings compared to before the presentation. I think this is because students in underrepresented groups want to see people that look like them in the virtual classroom. Gholdy Muhammad shared an activity that she uses during her teacher trainings in which she takes pictures of teachers working in small groups. Then, she projects them onto a large screen. “Their [teachers’] eyes go to their own faces. They look to find themselves. I believe students do the same in classrooms. They are seeking to find curriculum and instructional practices that honor the multiple aspects of who they are” (Muhammad, 2020, p. 69). By using these diverse female speakers, I attempted to honor the multiple aspects of my students in underrepresented groups. I purposefully designed activities for the STEM7 course that helped students learn about STEM professionals who shared cultural identities with the students. At Reach Cyber, 93% of the teachers are White, which stands in contrast to the student population where only about 50% of the students are White, and 50% are students in underrepresented groups. To offset this imbalance, I was able to seek out young, diverse STEM professionals to promote a sense of belonging for students in underrepresented groups in my virtual classroom.

4.1.3 Build Classroom Community to Nurture STEM Identity

In this section, I discuss the findings from the student-generated questions that formed the basis for learning during the STEM role models’ presentations. Analysis of the question data suggested the importance of building a classroom community and using an inquiry approach to online learning.

The results of the thematic analysis on the student-generated questions were fascinating. Through the analysis, I observed the progression of students’ questions as they evolved through five discernible stages. These five stages reminded me of the process of building community in the virtual classroom. Here are the commonalities I found.

In the first stage of the question progression, I found that questions were focused on making connections between the STEM professional and the student asking the question. This is similar to the communication factor in the classroom community. Teachers and students are interacting, looking for common interests. In the second stage of the progression, I found questions were focused on establishing trust. Similarly, in the process of building classroom community, being supportive of one another is an excellent way to build trust among members.

Once communication and support are established, students can continue building classroom community by simply collaborating on class activities and then progress to offering peer feedback on projects. These two steps are similar to the third and fourth stages of the question progression. Students created surface level questions for the STEM professionals at first, but then moved onto deeper level questions.

In the final stage of the question progression, I noticed worry still lingered in the students' questions for the STEM professionals. I also noticed this in my virtual classroom. Even though I made efforts to create a positive online learning experience (encouraging communication, support, collaboration, and constructive peer feedback), an element of anxiety still persisted in the virtual classroom community. A study by The Foundation for Blended and Online Learning found that students in blended and online schools are more likely to have health or social issues or be experiencing mental health challenges, such as anxiety and depression (Learning, 2017). The presence of anxiety in online students may have contributed to the questions that contained an element of worry for the STEM professionals' presentations.

Overall, it appeared that students were attempting to build a community with the STEM professionals through the progression of their questions. A STEM community, including partnerships between students and professionals, has the potential to benefit both groups (Nation & Hansen, 2021).

Regarding the data on student questions, there were two findings that were likely related. The first finding was that there was an increase in the total number of questions created by students throughout the first three intervention cycles. The second finding was that the questions grew in complexity over the same time period. It appeared that teaching students about questioning strategies using Norman Webb's Depth of Knowledge Framework (Hess, 2013) improved the quality of students' questions for the STEM professionals over the first three intervention cycles. Allowing students to create questions for the STEM professionals was an approach that is grounded in inquiry – that is students took ownership of their learning when they did this. Their questions formed the basis of their STEM learning. This inquiry-based approach makes students active participants in their learning and encourages engagement in the classroom community. One student said, "My favorite part of the presentation was when she answered my question." Inviting students to submit questions for the STEM professionals before their presentations proved to be a valuable teaching strategy for the virtual classroom because it encouraged self-questioning to construct knowledge (Herranen & Aksela, 2019).

4.1.4 The Possibility of STEM Identity Through STEM Learning

In this section, I discuss findings from the STEM identity surveys. The results were enlightening, but also inconclusive due to the limitations in an online learning environment.

The findings of this last inquiry question were inconclusive. By reviewing my students' responses on the STEM identity surveys, it would appear as if my students learned about STEM careers and made personal connections to the STEM professionals. This could be evidence of the development of STEM identity in my students. In 2017, the Center for Advancement of Informal Science Education (CAISE) asked a group of researchers how they conceptualized STEM identity in their various research efforts. In their studies of experiences designed to support STEM identity development, they explained that "a STEM identity can become an outcome of learning processes just as much as it is a component of the process of STEM learning" (Bell, 2018, p. 5). From this source, I deduced that STEM identity could be developed in my students through the interventions. With this in mind, I found many survey responses that met this criterion. However, there was a problem with this strategy. When reviewing the survey responses, I was assuming that students had watched the STEM professionals' presentations (either during Live Class sessions or the recordings inside Canvas) before they completed the STEM identity surveys. But due to technical limitations of the LMS, there is no way for me to confirm that students actually watched the presentation before completing the survey. For this reason, I cannot be certain that students' responses on the STEM identity surveys are the result of the STEM professionals' presentations or other sources. Therefore, while survey results were promising, I cannot be sure that the surveys provided evidence of STEM identity development in STEM7 students.

4.2 Limitations

The limitations of this study are inherent in online learning environments. It is the expectation set forth by Reach Cyber that the student alone completes the asynchronous coursework. However, there is no definitive way to confirm that the user completing assignments (such as the STEM identity surveys) inside Canvas is the student and not a caregiver or third party. It's also impossible to determine whether or not students watched the recordings of the STEM professionals inside Canvas before completing STEM identity surveys. This was a limitation on my ability to determine whether or not the survey responses represent actual evidence of STEM identity in my students.

There are several components of the STEM7 curriculum that constitute asynchronous coursework, including a variety of STEM-related assignments, projects, texts, and videos inside Canvas. All of these experiences have the potential to nurture a student's STEM identity. It was not possible to isolate one aspect of the STEM7 curriculum and conclude that it alone nurtured a student's STEM identity when many aspects are integrated in the asynchronous coursework. This was a limitation on my ability to determine if the STEM professional activities (inside Canvas) specifically nurtured students' STEM identity.

In the STEM7 course, it is not necessary to complete all the assignments in order to earn a passing grade. This was a limitation on my ability to collect poll data inside Canvas at the end of the semester. At least 30% of the total student enrollment in the STEM7 course did not complete all the assignments, including the end of semester poll. This was a limitation on my ability to assess the effectiveness of the intervention on all students in underrepresented groups in the STEM7 course.

4.3 Next Steps and Implications

The findings of my research imply that when online students engage in STEM learning related to STEM careers and interact with diverse STEM role models, these activities have the potential to nurture STEM identity in students. The intervention was successful, particularly for students in underrepresented groups, in part due to their engagement in STEM learning (through their questions) and attendance in the virtual classroom (during the STEM professionals' presentations). Due to these findings, I recommend that cyber charter schools reconsider their engagement and attendance policies. Currently, attending and engaging during Live Class sessions are optional for students in cyber charter schools. However, if these two policies were to change, there is a good chance that more students would attend presentations with STEM professionals during Live Class sessions and engage in conversations that could support their STEM learning and STEM identity development.

The interventions in this study can be applied in virtual schools and brick and mortar schools across the country and beyond. Educators can increase their students' STEM identity by using interactions with diverse STEM role models and an inquiry-based approach in their virtual classrooms. The luxury of online learning is that people can be connected virtually and easily. Web conferencing tools, like Zoom and Google Meet, can bring STEM professionals and students together over great distances without the hassle of in-person procedures. With the recent growth of virtual schools, implementation of this intervention has the potential to reach many online students and support them on their STEM journey.

5.0 Reflections

In 2020, online learning was jump-started on a massive scale and I wanted to better understand it. What better way to understand a system than to become a part of it and study it from the inside! For this reason, I took a job as an online teacher at Reach Cyber Charter School in 2021 and started a doctoral program to study STEM education and online learning at the University of Pittsburgh. Over the following three years, I developed into a scholarly practitioner. I learned that I can effect change in a system with many barriers.

Improvement science taught me to look for the right place to make a small change, implement the change, test it, and evaluate its effectiveness (Bryk et al., 2015). There were lots of problems in online learning, but I focused on identifying problems that I could address in my virtual classroom. I noticed that half of my students were from underrepresented groups in STEM and, through my studies, I discovered that these students needed additional support in STEM identity development. I designed an intervention (students asking questions and using diverse STEM role models) to be a small test of change within my curriculum (exploring STEM careers) and implemented it with successful results.

I learned the value of improvement. By evaluating the intervention cycles, I learned to improve my instruction so students could create better questions for the STEM professionals. I became familiar with Norman Webb’s Depth of Knowledge Framework and used it to teach students how to write complex questions. By performing t-test analysis, I learned new ways to evaluate quantitative data. Prior to this study, I had not analyzed qualitative data (through content and thematic analysis) on a large scale. These scholarly practices improved my research and evaluation skills.

Appendix A

Intervention #1 - Students' Questions for the Engineer (Interest in the person)
After all these years, how much money do you have saved up at all?
Did anyone inspire you if so who?
Did you have to a lot of school?
Did you play with Legos when you were a kid?
Did you wanted to be an engineer when you were younger?
Do you have a pet?
Do you have siblings? If so, are they engineers?
Does it make way for creative freedom?
Have you ever stressed so bad about something?
Have you had any other previous career ideas before choosing this one?
How does your family feel about your career choice? Are you close to your family? How does it impact your family life?
How long have you been working.
How many people do you work with?
How old were you when you created something for the first time?
How old were you when you started your job as an engineer?
How successful she thinks she is?
If you didn't do engineering, what would be your Plan B?
If you didn't go into engineering or CSI, what career would you have gone into?
In your part of engineering, are you pretty popular?
Out of all the things you made, what are you most proud of?
Tell me about yourself!
Was this always the goal or dream job?
What do you like to paint?
What do you love?
What do your parents do? Did they inspire you?
What interesting things have you done?
What is something you do for fun or relax?
What is your favorite book?
What is your favorite invention you made or someone else made?
What is your passion?
What led you to love and pursue engineering?
What part of the world are you in right now?
What started her career?
What was your favorite subject when you were a kid?
What would you do to fix the vending machine?
What's your favorite crime show that you watch?

What's your favorite hobby?
Where did you go to school?
Where do you live?
Who believed in you?
Who is your favorite inventor?
Why do you like STEM?
With engineering, is it something that runs in the family or is it one day that you thought about it and I want to try out for it?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Interest in the person)
...As well as what her hobbies were when she was younger?
Did you always want to do this job?
Did you ever have starter jobs before this one?
Did you have another career in mind before you chose this?
Did you want to be a cyber security specialist when you were younger?
Do u like it?
Do you family and friends support this job?
Do you have any passions?
Do you have other hobbies outside of work?
Do you have pets/a pet?
Do you have siblings, were state do you live in?
Do you have work life balance?
Do you look up to someone?
Do you see yourself doing this job forever?
Do you still connect with your family or your friends?
How do you cope with problems?
How do you entertain yourself if your ever of duty?
How often do you see your family
I want to ask Heather what made her to be a Cyber Security Specialist?
If not this job what job would you want?
If you didn't pursue this career what do you think you would be doing right now?
If you went to a school for all this how long did it take??
Was being a Cyber Security your first option?
Was cyber security always your dream job?
Was this the dream job?
Were you always into hacking and computers?
What are your favorite foods
What did you want to do before a cyber security specialist?
What did your family think of your job?
What do you do for fun, do you get holiday brakes?
What do you do for fun?
What do you do when you’re sick?
What do you like to do outside of work
What hobbies do you have outside of work?

What is the food like where you work at???
What school did you go to?
What was your dream job as a child?
What's your favorite game?
What's your Favorite grade/teacher/subject?
What's your favorite hobby?
Where did you go to college?
Where did you grow up?
Where do you live
Intervention #3 - Students' Questions for the Forensic Scientist (Interest in the person)
Are crime shows accurate? (opinion)
Are you thinking about doing this job for a long time?
Did you ever want to do geology?
Do you have any other jobs?
Do you have siblings and do they work close to your job or far away?
Do you like any crime shows?
Do you miss home when you go to training?
Have you ever watch those crime shows and you guess who it is before they tell you?
Have you watched CSI?
How old were you when you first started?
How old were you when you started the job?
If you could do any other job, what would it be?
What college did you go to?
What hobbies do you have outside of your job?
What is your favorite crime show?
When did you start your job?
Intervention #4 - Students' Questions for the Financial Advisor (Interest in the person)
Do you ever get stuck when working out finances?
How long have you worked here?
What are your favorite hobbies?
What kind of dance does your daughter do?
What made you want to be an Financial Advisor?
What school did you go to?
What were your hobbies as a kid?
Intervention #1 - Students' Questions for the Engineer (Interest in the job)
Any words she would say to an aspiring engineer?
Are you paid to make things?
Do you have any tips for kids who want to be engineers?
Do you travel for your job?
How did you become an engineer?
How did you get into Engineering?
How did you know what to do as an engineer?
How is it being a engineer?

How long does it take to become an engineer?
How much does an engineer make a year?
How would you explain what you do to someone who's never heard of it before?
What do you do as an engineer?
What is it like working as an engineer?
What made you want to be an engineer?
What position do you work in?
What things have you engineered?
What type of engineer are you?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Interest in the job)
Did you have to move away in order to pursue this career
Do you do this all day, or do you take breaks?
Do you get paid well
Do you have a leader?
Do you stay at home and work?
Do you travel for work?
Do you work normal hours (9-5pm)?
Does this career ever become tedious almost like a chore?
Have changed your beliefs for this job?
How does your job affect you?
How is it like being a Coast Guard security officer?
How long have you been at this job. Is this your dream job.
how long have you worked there
How many people ask you or your company for help? How do you help?
How much did you get paid?
How much do you do in one day?
How much do you get paid
How much does a cyber security specialist earn a day and how hard is it to get into this field?
How much hours do you work?
how much money do you make
I enjoy code and cyber security things. Do you have any tips for us?
Were you the only girl there?
What do you do on a daily basis?
What does a normal day look like for you?
What is it like to be a cyber security specialist?
What is the easiest part of your job?
What made you choose this job.
What made you want to do this job and what is the best part of this job?
What qualifications do you have to meet to become where you are?
What they do?

What's the most intense thing that you encountered on coast guard?
Why did you choose a cyber security specialist as a job?
Why did you choose Cyber Security?
Why did you chose to become a cyber security specialist?
Why did you get two jobs?
Why specifically did you choose the coast guard instead of a branch like the air force?
Intervention #3 - Students' Questions for the Forensic Scientist (Interest in the job)
Are there different levels for evidence technicians?
Did you learn this stuff in school?
Do you ever get disgusted or weirded out?
Do you ever get emotional during investigations?
Do you ever get sick when investigating a crime?
Do you have any achievements from the job?
Do you have to do continuing education for your job?
How did you get your job started?
How did you want to learn forensics?
How do you always know who did it?
How do you train or is there no training?
How many crimes do you solve a month or year?
How many hours do you spend each day on your job?
Is the job more solo or teamwork?
What awards do you get in this job?
What did you have to do to get your job today?
What experience is needed for this occupation?
What is an evidence technician?
What is forensic science?
What is it like (to be an evidence technician)?
What is the earning of the job?
What is the grossest thing you found at a crime scene?
What is the trickiest case you've ever been on?
What skills and/or education is needed to be a forensic scientist?
What was the longest investigation you had to do?
What was the scariest crime investigation you had to do?
What was your most gruesome crime scene you have seen?
What would you do if one of your coworkers got so traumatized from the crime scene that they were not able to look at blood or look at anything that happened at the scene?
Intervention #4 - Students' Questions for the Financial Advisor (Interest in the job)
Did you have to go to school?
What are finances?
What exactly do you do every day?

What is one of the most common misconceptions of your job?
What kind of school did you go to for this job?
Why is being a financial advisor important?
Intervention #1 - Students' Questions for the Engineer (Interest - favorable)
Are you happy being an engineer?
Do you enjoy it?
Do you like being an Engineer?
Is it fun to be an engineer?
What (part) of engineering are you most interested in and why?
What do you like the most about being a engineer?
What has been your biggest dream as an engineer?
What is your favorite part of engineering?
What is your favorite thing you have made as an engineer?
What was the biggest or most special project you have done as an engineer?
What's the most funny thing you could do that counts as engineering?
What's your favorite part of being an engineer?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Interest - favorable)
Do you have fun doing it or feel bad?
Do you like your job?
Is it fun being cyber security specialist?
What is the best part of the job?
What is the favorite thing about your job?
What is your favorite part of your job and your least favorite part of your job?
What is your favorite thing about being a Security Specialist?
What's the best part of your job?
Intervention #3 - Students' Questions for the Forensic Scientist (Interest - favorable)
Do you like your job?
What was the best day on the job?
Intervention #4 - Students' Questions for the Financial Advisor (Interest - favorable)
NA
Intervention #1 - Students' Questions for the Engineer (Interest with some worry)
Hey Mary! Quick Question, as an engineer what has been your biggest challenge (work) yet?
Is being an engineer hard?
Is it stressful?
What challenges have you faced as an engineer?
What do get angry at as an engineer with some of your work?
What if something fails and your deadline coming up what do you do?
What the hardest thing about being an engineer?
What will be the most challenging part of this job for you?
Who would you turn to for help?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Interest with some worry)
Is it difficult to work as a cyber security specialist?
Did you ever feel like giving up? And if you did, what kept you motivated to keep going?

How hard is your job?
How hard is your job?
Is it hard to be a cyber security specialist?
Is it hard to get into this field?
Is your job hard? Did you ever have to fatally hurt people?
Was it hard to get in?
What do you do if you fail?
What has been the hardest part of being a cyber security specialist?
What is the hardest part of your Job?
What is the hardest part of your job?
What is the hardest thing you have done in this job?
What is the worst cyber threat you got?
When you first got in was easy going hard or was it hard right off the bat?
Intervention #3 - Students' Questions for the Forensic Scientist (Interest with some worry)
Do you ever get scared?
Are you ever scared on the job?
Don't you ever feel pressured really bad when everyone is counting on you?
Have you ever messed up while doing your job?
On a scale of 1-10, how hard is this job?
Was it ever really difficult, where you needed help finding the evidence and taking pictures?
Where there a scenario where you were in danger?
Intervention #4 - Students' Questions for the Financial Advisor (Interest with some worry)
What if someone gets aggressive?
How hard is your job for you from 1-10?
What is the hardest part of your job?
Intervention #1 - Students' Questions for the Engineer (Competence)
Are blueprints used during a process?
Do you like to work alone or in a group when you are working?
Do you spend more time in the office graphing stuff or do you spend most of your time out in the field building things or is it an even mix?
Do you use the same problems for something else if you end up failing?
Have there been any major process killers?
How did your engineering skills developed?
How do you spend your day?
How does engineering improve your life?
What are some things you built?
What exactly do they do?
What is the hardest problem you had to solve?
What kind of processes do you come up with?
What problems have you solved?
What type of job does a process engineer as in taking temps for certain things or building things?
What was your very first engineering design?

What would you do if you were unable to solve a problem?
When you are an engineer to you get reference charts for everything? Or do you have to solve the problems first and then also during your work?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Competence)
Are there any similarities between military and cyber security?
Are you an independent worker?
Could you fight since you are in the army?
Did u ever have to unhack?
Did you ever catch a hacker?
Did you ever have to hack into your own stuff?
Did you ever have to track someone down while doing cyber security?
Did you hack someone before?
Do you always have to find the hackers?
Do you eat rations like in the real army?
Do you ever have to hack a hacker or hack your own stuff to stop hackers?
Do you have social media? What is someone got into your account to your social media?
Do you help people recover from internet Wi-Fi attacks such as direct denial of service attacks?
Do you ride on a ship?
Do you work alone or do you work with others?
Have you ever dealt with any other branches in the military or government?
Hey Mrs I would like to know what it feels like to get contacted to eliminate a cyber threat?
How did you prepare for your job?
How many computers has she had to hack?
How old do you have to be to train?
If you cancel the download halfway would the hacker still be able to get into your computer?
What branch of the military are you in?
What does the military have you do aside from Cybersecurity?
What does your job do for the world?
What happens if someone hacks into your stuff what do you do?
What if they end up hacking into your system and it can't be stopped?
What kind of security issues do you encounter most?
What type of military are you in (or were in)?
What was your biggest project when working for the government?
Intervention #3 - Questions for the Forensic Scientist (Competence)
Are crime scenes dangerous?
Are there tracker animals to find smells of hidden objects?
Can you determine the gun by the bullets?
Can you tell your family/friends about your cases or are they confidential?
Did you ever have to catch a criminal that was most wanted?
Do any of your investigations involve family members or people on your team?

Do you get to keep Sandy as a pet after you retire?
Do you have to learn more about photography because of your job?
Do you have to wear a bunny suit?
Do you track the fingerprints?
Do you use floor plans?
Do you use UV scales?
Has there ever been more than one crime scene at the same time?
Have you ever had to go to several different locations just to solve one case?
How hard is it to find evidence or does it depend on the situation?
How long does it take to find evidence?
How long does it take to track fingerprints?
Is it a horrid smell?
Is part of your job classified?
Were there any cases never solved?
What can't the police interfere with the crime scene?
What dog breed is Sandy (the police dog)?
What if the victim doesn't give you enough information?
What if there is no evidence and no lead?
What if there is no evidence at all?
What if there is no evidence?
What if you touch the evidence and your fingerprint goes on it?
What if you're working on a murder case and the body wasn't there?
What notes do you take?
Which crime is the hardest to figure out?
Intervention #4 - Students' Questions for the Financial Advisor (Competence)
Do you ever have to give advice about other things (not regarding finance) in order to give the best financial advice?
Are you required to complete a certification process to become a Financial Advisor?
Can you use a calculator?
Do you use science with your job? If so, how?
Does this job help the stock market?
Is a college degree a requirement to become a Financial Advisor?
What school did you go to to learn all of your financial stuff?
Intervention #1 - Students' Questions for the Engineer (Self-Recognition)
Am I technically an engineer if I create things with what I find around me?
Did you want to be in a different field before choosing being an engineer?
How did you know you wanted to become a engineer?
If I were to do engineering, what would I do?
When did you know that STEM was what you wanted to do?
Intervention #2 - Students' Questions for the Cyber Security Specialist (Self-Recognition)

Did you always know that this is what you wanted to do?
How did you know you wanted your job?
When did you know that your career path was the right one for you?
Intervention #3 - Students' Questions for the Forensic Scientist (Self-Recognition)
Did you ever want to do something else besides this?
Do you think you're a detective? You're almost like a detective.
Have you always wanted to be a forensic scientist?
How did you know that you wanted to be a forensic scientist?
Were you always fascinated with forensic science?
What age were you when you wanted to study forensic science?
When you were younger, did you like mystery stuff? Did that provoke you to want to be a forensic scientist?
Intervention #4 - Students' Questions for the Financial Advisor (Self-Recognition)
Did you always want this job or do you have a different dream?
If you weren't a financial advisor, where do you think you would be?
Was this your dream job when you were little?
Intervention #1 - Students' Questions for the Engineer (Recognition by Others)
Did you ever have any problems being a woman and a person of color in the engineering business?
Do you face challenges in a mainly male-dominated workplace?
Do your co-workers treat you in an appropriate way? Kindly, respectfully, etc.
Intervention #2 - Students' Questions for the Cyber Security Specialist (Recognition by Others)
Do you have family or friends close to this field?
Have you ever been looked down on in your position since you’re a woman?
What is it like being a woman in a male dominated industry?
Intervention #3 - Students' Questions for the Forensic Scientist (Recognition by Others)
Do other people tell you that you couldn't do it? If yes, did that make you work harder?
Intervention #4 - Students' Questions for the Financial Advisor (Recognition by Others)
If you were to recommend this job to others what would you describe it as?

Appendix B

PDSA Results - Cycle #1

Test Title:	The influence of diverse STEM professionals on the STEM identity of cyber school students	Date:	September 2023
Tester:	Toni Stith	Cycle #:	One (Engineering)
What Change Idea is being tested?	Utilize diverse STEM professionals that reflect students' cultural identities to increase students' STEM identity while exploring STEM careers	Driver:	Expand students' knowledge of STEM professions (secondary driver)
What is the overall GOAL of the test?	Testing the hypothesis that utilizing STEM role models in a virtual classroom will increase the STEM identity in underrepresented groups of students		

1) PLAN **Details: Describe the who/what/where/when for the test. Include your data collection plan.**		
The teacher will facilitate a lesson on engineering. Students will generate questions for the engineer. The teacher will give questions to the engineer before the presentation. The engineer will answer the students questions in a presentation facilitated during a synchronous class session. Students will engage with the engineer after the presentation. Students will complete a poll before and after the presentation. Students will complete a survey based on the presentation.		
Questions: Questions you have about what will happen. What do you want to learn?	**Predictions:** Make a prediction for each question. Not optional.	**Data:** Data you'll collect to test predictions.
Will students' learn about engineering from the diverse engineer? (Secondary driver: expand students' knowledge of STEM professions)	I predict students will learn about engineering and the engineer.	I will examine the questions that students create for the engineer and

2) DO Briefly describe what happened during the test, surprises, difficulty getting data, obstacles, successes, etc.
Students created 90 questions for the engineer. Engineer presented for a half-hour. Students (all were females) asked 16 more questions after the presentation concluded. These questions were well-worded and better than many of the questions submitted before the presentation.
What were your results? Comment on your predictions in the box below. Were they correct? Record any data summaries as well.
Students created 106 questions in total for the engineer. Students submitted 164 completed surveys after the presentation. There was evidence of STEM learning in the answers from the students' questions in the survey responses.

		the survey responses.	
Will students develop STEM identity from the diverse engineer's presentation? (Primary driver: classroom engagement)	I predict that the engineer's presentation will increase the students' STEM identity.	I will examine the poll results before and after the presentation as well as the survey responses.	Poll results indicated that there was an increase in the percentage of students with a moderate to high STEM identity from the beginning (68%) to the end (72%) of the presentation.

3) STUDY What did you learn?
The teacher learned that students' questions for the engineer nurtured students' STEM identity. Students were capable of asking well-worded questions, as evidenced by their questions for the engineer after the presentation. The teacher concluded that support in writing effective questions might help students create well-worded questions before the presentation.

4) ACT Describe modifications and/or decisions for the next cycle; what will you do next?
The teacher researched strategies for instruction in writing effective questions. In response, Norman Webb's Depth of Knowledge framework for questioning will be used as a tool for teaching students to write well-worded questions during the next cycle.

Appendix C

PDSA Results - Cycle #2

Test Title:	Teaching questioning strategies to improve students' questions for STEM professionals	Date:	October 2023
Tester:	Toni Stith	Cycle #:	Two (Cyber Security)
What Change Idea is being tested?	Increase students' knowledge of effective questioning strategies	Driver:	Expand students' knowledge of STEM profession (secondary driver)
What is the overall GOAL of the test?	Testing the hypothesis that providing support in questioning strategies in a virtual classroom will improve students' questions for the STEM professional		

1) PLAN **Details: Describe the who/what/where/when for the test. Include your data collection plan.**		
The teacher will ask questions that represent the four levels of questions in Norman Webb's Depth of Knowledge (DOK) framework. The teacher will then introduce the DOK framework and explain the question progression. The teacher will ask questions and the students will identify the numeric level of each question. The teacher will encourage students to create questions in the range of levels two through four for the STEM professional. The Plan and data collection from cycle #1 will be repeated.		
Questions: Questions you have about what will happen. What do you want to learn?	**Predictions:** Make a prediction for each question. Not optional.	**Data:** Data you'll collect to test predictions.

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2) DO Briefly describe what happened during the test, surprises, difficulty getting data, obstacles, successes, etc.
Students were able to identity teacher-led questions in levels one and two with ease but were indecisive in identifying questions in levels three and four. Students created 128 questions for the specialist before the presentation and asked 7 questions after the presentation. The Plan and data collection from cycle #1 was executed.
What were your results? Comment on your predictions in the box below. Were they correct? Record any data summaries as well.

Will students create well-worded questions for the diverse cyber security specialist? (Secondary driver: expand students' knowledge of STEM professions)	**I** predict students will create well-worded questions for the diverse specialist.	**I** will examine the level (according to the DOK framework) of each question that students create for the specialist.	There was an increase in the number of Competence and Interest category questions that students created for the specialist. This resulted in an overall increase in questions from cycle #1. Of the 135 questions created, over half of them were level one questions and over a quarter were level two questions.
Will students learn about cyber security from the diverse specialist? (Secondary driver: expand students' knowledge of STEM professions)	**I** predict students will learn about cyber security and the specialist.	**I** will examine the questions that students create for the specialist and the survey responses.	Students created 135 questions in total for the cyber security specialist. Students submitted 153 completed surveys after the presentation. There was evidence of STEM learning in the answers from the students' questions in the survey responses.
Will students develop STEM identity from the cyber security diverse specialist's presentation? (Primary driver: classroom engagement)	**I** predict that the specialist's presentation will increase the students' STEM identity.	**I** will examine the poll results before and after the presentation as well as the survey responses.	Poll results indicated that there was an increase in the percentage of students with a moderate to high STEM identity from the beginning (64%) to the end (79%) of the presentation.

3) STUDY What did you learn?
The teacher observed an increase in the number of questions created for the STEM professional. There were more questions that asked specifically about the STEM professional's job and responsibilities than in cycle #1. Despite the instruction in questioning strategies, 58% of the questions students created were at level one in the DOK framework. The teacher concluded that further support would be needed in writing questions at levels two and higher.

4) ACT Describe modifications and/or decisions for the next cycle; what will you do next?
The teacher examined the STEM7 curriculum and determined an ideal lesson to integrate another lesson on questioning strategies within the regular STEM7 curriculum. Students will practice writing questions with teacher support in a synchronous class session. This will be a different class session than the lesson that creates questions for the STEM professional.

Appendix D

PDSA Results - Cycle #3

Test Title:	Apply questioning strategies in various STEM7 curriculum to improve students' questions for STEM professionals	Date:	November 2023
Tester:	Toni Stith	Cycle #:	Three (Forensic Science)
What Change Idea is being tested?	Practice questioning strategies in a variety of lessons within the STEM7 curriculum	Driver:	Expand students' knowledge of STEM profession (secondary driver)
What is the overall GOAL of the test?	Testing the hypothesis that applying the questioning strategies to different lesson within the STEM7 curriculum will improve students questions for the STEM professional		

1) PLAN **Details: Describe the who/what/where/when for the test. Include your data collection plan.**		
The teacher will encourage students to write questions about tabletop games during a synchronous class session. The teacher will encourage students to write questions about the games that are at levels two through four. The teacher will identity the levels of all the questions that students create about the tabletop games. The teacher will repeat this process for two games. The teachers will group the questions according to their levels and discuss commonalities among the questions. The Plan and data collection from cycle #2 will be repeated.		
Questions: Questions you have about what will happen. What do you want to learn?	**Predictions:** Make a prediction for each question. Not optional.	**Data:** Data you'll collect to test predictions.

2) DO Briefly describe what happened during the test, surprises, difficulty getting data, obstacles, successes, etc.
Students created about 24 questions for each of the two games in the synchronous class session. The questions ranged from level one to level four in the DOK framework. One week later, students created (at least) 74 questions for the forensic scientist before the presentation and asked 17 questions after the presentation. The Plan and data collection from cycle #2 was repeated.
What were your results? Comment on your predictions in the box below. Were they correct? Record any data summaries as well.

Will students create well-worded questions for the diverse forensic scientist? (Secondary driver: expand students' knowledge of STEM professions)	I predict students will create well-worded questions for the diverse scientist.	I will examine the level (according to the DOK framework) of each question that students create for the specialist.	There was an increase in the number of Competence and Self-Recognition category questions that students created for the scientist. Of the questions created, nearly a quarter of the questions were level three - a large increase from cycle #2. The number of level one and two questions decreased.
Will students' learn about forensic science from the diverse scientist? (Secondary driver: expand students' knowledge of STEM professions)	I predict students will learn about forensic science and the scientist.	I will examine the questions that students create for the specialist and the survey responses.	Students created 91 questions in total for the cyber security specialist (some questions were lost due to a file overwrite error). Students submitted 129 completed surveys after the presentation. There was evidence of STEM learning in the answers from the students' questions in the survey responses.
Will students develop STEM identity from the diverse forensic scientist's presentation? (Primary driver: classroom engagement)	I predict that the scientist's presentation will increase the students' STEM identity.	I will examine the poll results before and after the presentation as well as the survey responses.	Poll results indicated that there was an increase in the percentage of students with a moderate to high STEM identity from the beginning (63%) to the end (88%) of the presentation.

3) STUDY What did you learn?
The teacher observed an increase in the number of questions created for the STEM professional. Students asked more questions in the Self-Recognition category than in previous cycles. Questioning strategies were used in a variety of lessons in STEM7 class. There was an increase in student-generated questions at level three and a decrease in questions at level one. The teacher concluded that integrating questioning strategies into further STEM7 lessons could support students in writing effective questions.

4) ACT Describe modifications and/or decisions for the next cycle; what will you do next?
The teacher reflected on the calendar and the number of school days remaining in the STEM7 class. The teacher repeated the Plan and data collection from this cycle but did not implement a test of change. Similar to previous cycles, students practiced writing questions in a variety of lessons before creating questions for the financial advisor's presentation in January 2024.

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