frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 16 May 2025
DOI 10.3389/feduc.2025.1547938

Graduate STEM students as role models for high school students

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RECEIVED 18 December 2024
ACCEPTED 29 April 2025
PUBLISHED 16 May 2025

CITATION
Topliceanu A-M, McCance KR, Blanchard MR and Sollinger J (2025) Graduate STEM students as role models for high school students.
Front. Educ. 10:1547938.
doi: 10.3389/feduc.2025.1547938

Introduction: STEM graduates are important to U.S. research development and innovation, adding diverse perspectives and talents to communities and the academy, and enhancing the financial stability of universities. Graduate STEM students' work on funded research occasionally engages them in outreach opportunities with K-12 schools and students. Yet, few graduate students participate in professional development that prepares them for these roles.

Methods: This exploratory, descriptive case study chronicles the experiences of eight graduate STEM students (six international and two domestic) who visited high school classrooms, via Zoom, as part of a federally funded sustainability project. This study investigated the factors graduate STEM students considered most important when planning and implementing their Zoom outreach visits, what they perceived as the supports, benefits, and challenges, and in what ways their Zoom visits and reflections correspond to the Motivational Theory of Role Modeling.

Results: The findings demonstrate graduate students' focus on engaging students, the relevance of science to society, and job opportunities in STEM fields. Graduate students perceived challenges associated with making the complex academic language and research understandable to high school students and felt supported by university team members and high school teachers.

Discussion: Implications for role models and professional development for graduate STEM students are discussed, along with novel contributions to the theoretical framework.

KEYWORDS

graduate students, international, STEM role models, high school students, scientists in the classroom, sustainability

1 Introduction

STEM (Science, Technology, Engineering, and Mathematics) workers in the United States (U.S.) are in high demand. There were 29 million STEM workers in 2011 and 30.9 million in 2021 (NCSES, 2023). STEM jobs are expected to grow 10.8% by 2031, twice as fast as all occupations (Krutsch and Roderick, 2022). However, there is disproportionate racial representation in the STEM workforce, such that Hispanic, Black, American Indian, and Alaskan Native individuals represent less than one-fourth of STEM workers (NCSES, 2023). Additionally, women are underrepresented in STEM fields, with approximately 35% of the STEM workforce occupied by women in 2021 (NCSES, 2023). Despite progress in the last decade (Fry et al., 2021), diversifying the U.S. STEM workforce remains a national priority and challenge.

Graduate STEM students work as research and teaching assistants (Ozturgut, 2013; Wan et al., 2020) and occasionally are engaged in K-12 outreach programs as 'scientists in the classroom' (Ufnar et al., 2012). These outreach programs have the benefit of "raising science literacy and increasing the size and diversity of the science workforce" (Laursen et al., 2007,

p. 49). Outreach programs can nurture students' interest in science, augment "students' awareness of ongoing scientific research" (Clark et al., 2024; Clark et al., 2016, p. 2), and increase student achievement and positive attitudes toward scientists (Taylor et al., 2022). Through K-12 outreach, graduate STEM students have the potential to serve as role models and motivate students' STEM interests and goals (Morgenroth et al., 2015). This is important, especially during high school, when adolescents begin making career-related decisions (Pringle et al., 2020). Role models who are perceived as attainable, such as graduate students, can increase role aspirants' expectations of success (Gartzia et al., 2021). STEM graduate students can benefit from outreach programs by improving their teaching and communication skills (Laursen et al., 2012). Due to the complexity of academic language and research specialization, scientists often consider it difficult to explain their work to lay audiences (Salita, 2015). There is research on graduate STEM students visiting in-person K-12 classrooms (e.g., Hanson et al., 2020; Laursen et al., 2007; Ufnar and Shepherd, 2021), but little is known about their planning nor is there information about implementing high school classroom visits through a synchronous online platform, such as Zoom.

There are several reasons it is important to understand more about graduate STEM students' involvement in K-12 classrooms. First, there is a growing number of graduate STEM students, and most grant projects require broader impact activities that likely include more students in science outreach programs (e.g., NSF, 2008). Second, graduate STEM students need additional skills, such as communication and teaching skills, that will prepare them for a variety of careers (NSF, n.d.). Third, quality presentations by STEM role models as part of a STEM outreach program could have the potential to influence high school students' workforce pathways, by potentially sparking the adolescents' interest in science careers (Clark et al., 2016; Clarke et al., 2019). This study seeks to refine our understanding of both domestic and international graduate students as STEM role models in an online context, and their reflections on their planning and Zoom classroom visits.

2 Literature review

2.1 Graduate STEM education

STEM graduates and students make valuable contributions to innovation, research, the economy, national security, and the health and well-being of communities (NASEM, 2018). The U.S. system of graduate STEM education is robust, as reflected by the substantial number of domestic and international STEM students (NASEM, 2018). As of 2024, Science, Engineering, and Health Sciences programs enrolled approximately 320,000 full-time master's students and 260,000 full-time doctoral students, and over 45% of whom were international (Smith et al., 2024). Enhanced education, prospective career opportunities, accomplished advisors, and professional communities are some benefits that international graduate students experience while studying in the U.S. (Gesing and Glass, 2019). International graduate STEM students add diversity to institutions' communities, enhance academic life, and contribute financially to the academic institutions and cities where they live (Moglen, 2017; Ruiz, 2014).

STEM graduates find employment in a wider array of jobs upon graduation than in the past. In 2017, the NSF reported that 39% of the science and engineering doctorate recipients were employed in a four-year higher educational institution, 3.7% in other educational institutions, 35% in private, for-profit companies, 6.8% in the private, nonprofit sector, 6.4% in the federal government, and 2.2% in state or local government (NCSES, 2017). Despite its strengths, Leshner and Scherer (2019) recommend implementing changes in U.S. graduate STEM education, including further developing STEM students' technical and leadership skills and communication with lay audiences, to prepare students for the wider range of available jobs.

2.2 Professional development of graduate STEM students

Although graduate STEM programs vary from one institution to another (Leshner and Scherer, 2019), they follow an apprenticeship model, in which graduate students are trained by faculty mentors who conduct highly specialized research (Atkinson and Slatta, 2021). Harshman (2020) conducted a literature review and found that doctoral chemistry students are "overly specialized in their training" but "ill-prepared" (p. 259) for nonacademic careers and teaching positions. In addition to gaining advanced knowledge in their STEM field, it is vital for graduate students to hone other skills and have opportunities to participate in professional development in communication, writing, mentoring, leadership, nonacademic careers, and teaching or educational research programs (Border and Von Hoene, 2010; NASEM, 2018; Nguyen and Yao, 2022). The National Academies of Sciences, Engineering, and Medicine recognize the importance of professional development activities and argue that "professional development experiences do not detract from core elements of the Ph.D." (NASEM, 2018, p. 113).

Communication and teaching are important skills needed by graduate STEM students. Ganapati and Ritchie (2021) investigated how the professional development available to doctoral STEM students supports their pursuit of non-academic and non-research and development jobs. Analyzing the responses to a mixed-methods questionnaire of 176 STEM doctoral students and graduates, Ganapati and Ritchie reported that alumni listed teaching skills as the third most valued professional development activity they experienced during their doctoral program, after attending conferences and gaining research and writing skills. Yet, Atkinson and Slatta (2021) noted that STEM doctoral students might not have the necessary teaching skills required for jobs other than research. In a mixed-methods study involving 688 doctoral students from a private, research-intensive university, Heflinger and Doykos (2016) found that doctoral students felt trained to write academic papers (89%), present at conferences (94%), and had current knowledge of the advances in their field (96%), but they felt less trained in teaching (63%).

The structure of professional development matters. For instance, short-term engagement with professional development was less effective than long-term engagement at enhancing biology teaching assistants' beliefs about teaching (Lee, 2019). DeChenne et al. (2012) reported that the STEM graduate teaching assistants who spent more time engaging in professional development had more positive perceptions of their learning about how to teach. Additionally, Fong et al. (2019) found that reflection on teaching experiences during professional development was critical for increasing engineering teaching assistants' self-efficacy.

The NSF Graduate STEM Fellows in K-12 Education Program (GK-12) immersed STEM graduate students in K-12 classrooms, but was discontinued more than a decade ago (AAAS, n.d.). One of the GK-12 program's goals was to include training that would prepare graduate STEM students for a wide range of careers as well as improve their communication, teaching, and collaboration skills (NSF, n.d.). Graduate STEM students may benefit from more pedagogical training and teaching practice, not only when joining the job market, but also when teaching undergraduate students as teaching assistants (Love Stowell et al., 2015; Nguyen and Yao, 2022).

2.3 Challenges faced by international graduate STEM students

International graduate STEM students face cultural, social, racial, and financial challenges while studying in the U.S. (Han and Appelbaum, 2016; Rodriguez et al., 2024). Proficiency in English skills is a common barrier faced by many nationalities of graduate STEM students. For example, a study found that Mexican engineering graduate students had difficulty passing the Test of English as Foreign Language (TOEFL) exam (Alves et al., 2015). Jiang (2014) found that Chinese graduate STEM students perceived that their English education in their home country emphasized reading and writing, while speaking and listening lacked instruction. As a result, English proficiency became a source of criticism of these international students from domestic undergraduate students. Interviews carried out by Lim et al. (2021) and Rodriguez et al. (2024) revealed that international STEM students who were proficient in English still received complaints about their accents, had lower teaching evaluations, and perceived microaggressions from the students they taught. In a study of international doctoral engineering students who worked as teaching assistants, Agrawal and McNair (2021) found that their linguistic abilities varied due to their backgrounds and prior teaching experiences. However, the engineering content alleviated some of the language challenges. More so, their linguistic abilities improved as they gained skills as teaching assistants.

2.4 Scientists in the classroom

Students who are informed about careers in STEM are more likely to obtain a STEM job (Blotnicky et al., 2018; Kitchen et al., 2024). When students are engaged in "more authentic scientific practices and experience what 'real' scientists do," their interest in science and STEM degrees increases (Philip and Azevedo, 2017, p. 528). These two considerations have important implications for designing programs that raise STEM career awareness, with the ultimate goal of improving STEM workforce pathways (Habig et al., 2020). One method to increase awareness and interest in STEM careers is to have graduate STEM students serve as 'scientists in the classroom' by visiting K-12 classrooms and interacting with students. 'Scientist in the classroom' is "a common outreach model" that invites scientists to schools to "stimulate student learning, interest in science, and consideration of science careers" (Laursen et al., 2007, p. 49) and promote K-12 students' motivation for STEM (Vennix et al., 2016, 2023). Relevant literature on scientists in the classroom shows that K-12 students benefit from this type of program, including expansion of their science interests and comprehension (Clark et al., 2016). Alpert (2018) posited that bringing scientists into K-12 classrooms is not about the amount of information delivered but about how profoundly the scientists capture students' enthusiasm and interest.

Research on graduate STEM students' participation as scientists in the classroom primarily has focused on the outreach outcomes and benefits for graduate students, undergraduates, K-12 students, and teacher partners (Clark et al., 2016; Knippenberg et al., 2020; McClure et al., 2020). In a study of 24 graduate science students, Laursen et al. (2012) found that 22 participants expressed an increase in their "teaching, communication, and management skills; understanding of issues related to education and its social development; personal development; and career skills" (p. 55). In a related study, semi-structured interviews with 24 science and engineering graduate students confirmed that participation in these outreach programs enhanced their career options or facilitated a change in their career direction (Laursen et al., 2007). Similarly, Ufnar and Shepherd (2021) conducted a survey study with 83 graduate students and postdoctoral fellows who co-taught elementary and middle school students one day each week. They found that the majority (90%) of the scientists in the classroom felt that they improved their teaching and communication skills, and their ability to explain science to a lay audience.

Communicating with non-scientists is a fundamental ability that scientists and STEM graduates need to possess (Brownell et al., 2013; NASEM, 2018) to capture their audiences' interest and increase their motivation for STEM. Due to the complexity of academic language, research, and extensive specialization, scientists consider it challenging to explain their work to non-scientists (Salita, 2015). Strategies such as avoiding jargon and using clear, structured texts and presentations are some ways to communicate science effectively to lay audiences (König et al., 2024). Graduate STEM students are interested in learning how to explain their research to a broader audience (NASEM, 2018), but lack institutional preparation for communicating science to lay audiences (Brownell et al., 2013). In fact, Rose et al. (2020) found that 57% of science faculty ($n = 6{,}242$) believed science communication and public engagement were not important to administrators, "contributing to a perceived lack of institutional support" (p. 1275).

2.5 STEM role models

There is research in education about role models and their potential to broaden aspirations for STEM careers at post-secondary and K-12 levels (e.g., Conner and Danielson, 2016; Fried and MacCleave, 2009; McAlexander et al., 2024), but most of it focuses on the student perspective. Exposure to STEM role models was associated with increased interest in STEM and a sense of belonging in college among undergraduate (STEM and non-STEM) students who read biographies that challenged STEM stereotypes (Shin et al., 2016). Also, faculty STEM role models influenced graduate students' STEM career decisions, but not uniformly; fewer female graduate students identified role models as having an impact on their job decisions compared to males (Fried and MacCleave, 2009). At the K-12 level, Conner and Danielson (2016) found that scientists who were acting as role models in classrooms changed elementary and middle school students' ideas about scientists, science self-concepts, and interest in participating in science. The format of role model interventions also matters, whereby students benefit more from being able to see role models than reading about them or only listening to their voice (De Gioannis et al., 2023). Researchers also highlight the importance of the personal characteristics of the scientist in the classroom and implications for professional development for scientists. Conner and Danielson wrote, "we suggest that programmes training scientists emphasize empathy and positive interactions with students, as the perception of a scientist as nice and friendly appears to be linked to many of our results" (Conner and Danielson, 2016, p. 15).

3 Framework: the Motivational Theory of Role Modeling

The Motivational Theory of Role Modeling (Morgenroth et al., 2015) served as the theoretical framework for this study. This theory draws on expectancy-value theories of motivation and the literature on role models (e.g., Lockwood, 2006; Merton, 1957). A role model refers to a person, such as a scientist, whose actions provide examples of behaviors for another person, such as a high school student. Numerous studies have reported on the positive effects of role models (e.g., Fried and MacCleave, 2009; González-Pérez et al., 2020; Passi and Johnson, 2016). Passi and Johnson (2016) found that role models assisted graduate students with developing professionalism, identity, and shaping their career choices. Recently Gartzia et al. (2021) conducted four studies with over 2,000 students to empirically test whether attainable role models could lead role aspirants to adopt more ambitious goals. They found that the role models' career needed to be perceived as attainable, and stressed the importance of having role models who embody representations of the possible, particularly from members of minority groups. Gladstone and Cimpian (2021) found that role models should be "meaningfully similar" (p. 16) to students in their identity and/or on a deeper level, such as sharing similar values or persisting through challenges.

In their Motivational Theory of Role Modeling, Morgenroth et al. (2015) noted three common themes that emerge from various definitions of role model. They define role models as "individuals who influence role aspirants' achievements, motivation, and goals by acting as *behavioral models, representations of the possible*, and/or *inspirations*" [emphasis added] (p. 468). The framework proposes that role models (e.g., STEM graduate students) influence role aspirants' (e.g., high school students') outcomes, such as their motivation and adoption of goals, through role modeling processes from the perspective of role aspirants and their perceptions (Figure 1). For instance, role aspirants' perceptions of role models' goal embodiment, attainability, and desirability influence the role aspirants' expectancy and value of goals. This is accomplished by initiating vicarious learning, personal identification, and internalization, and changing role aspirants' perceptions of barriers and self-stereotyping.

The framework is situated from the perspective of the role aspirants, such as high school students or other individuals, by connecting the role model functions (e.g., behavioral models, representations of possible, and inspirations) with associated variables (e.g., role aspirant attributes, role model attributes and qualities, mechanisms, and role aspirants' outcomes). In contrast, the current study considers the Motivational Theory of Role Modeling from the perspective of the role models, graduate STEM students (see Figure 1). The focus is on how STEM graduate students may have created opportunities "to increase role aspirants' motivation, reinforce their existing goals, and facilitate their adoption of new goals" (Morgenroth et al., 2015, p. 465) during their K-12 outreach.

In the context of the current study, when graduate STEM students visit K-12 classrooms via Zoom, they potentially act as *behavioral models* for the high school students by showing them part of their research and how it is done. Behavioral models demonstrate "how to achieve" a goal (Morgenroth et al., 2015, p. 471) through the skills, strategies, and actions they display for others to observe and learn from. Graduate STEM students can be *representations of the possible*, by showing K-12 students that "something is possible" (p. 467), within reach. Students may see a pre-existing or new goal as being more attainable, especially if they view role models as "successful members of one's own group" (p. 467). The graduate students can act as *inspirations* with the potential to motivate high school students to take up new goals or "strive toward…something better than before" (p. 468). Their interactions and presentations could capture students' interest and make science/engineering careers and/or working in academia "desirable and worth striving for" (p. 468).

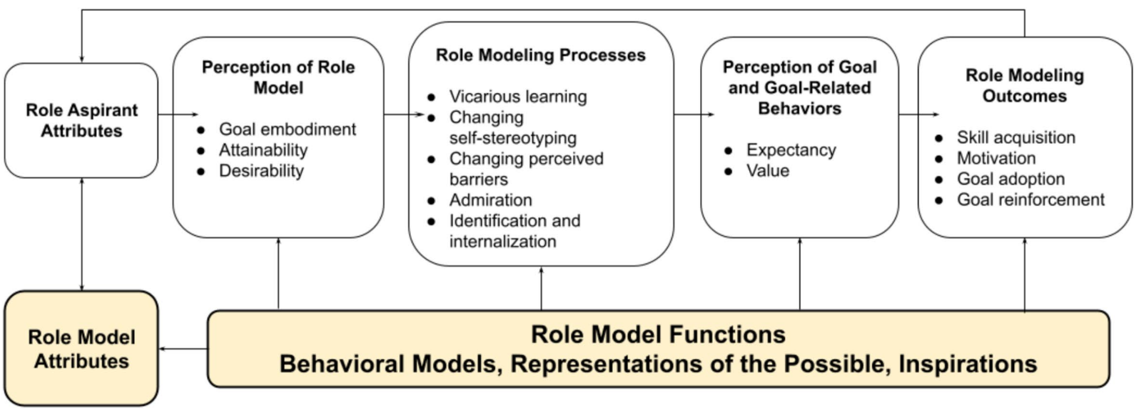

FIGURE 1
Overview of the Motivational Theory of Role Modeling (Morgenroth et al., 2015), highlighting the current study's focus on the role models and their functions in yellow.

4 Research design

This is an exploratory, descriptive case study (Merriam, 2001). The bounded case was a group of international and domestic STEM graduate students who were involved with a grant-funded program whose broader impacts were aimed at stimulating U.S. high school students' interest in biodegradable, flexible electronics and related career pathways. The descriptive approach was achieved by incorporating multiple data sources and providing a rich case description. The case study design allowed for the exploration of the STEM graduate students' novel involvement in the high school classroom visits and a deeper understanding of the complexities of the planning and implementation by drawing on their unique backgrounds and experiences.

4.1 Research questions

1. How did international and domestic STEM graduate students plan and implement their Zoom visits?
2. How did international and domestic STEM graduate students describe the supports, benefits, and challenges they experienced when preparing for and visiting high school classrooms via Zoom?
3. In what ways did graduate students' Zoom visits and reflections on those visits correspond to the Motivational Theory of Role Modeling?

5 Methods

5.1 Context

A four-year National Science Foundation (NSF) grant involved STEM and Education colleges from three large, public and private research universities in the Mid-Atlantic and Northeast U.S. The grant program was facilitated by twelve graduate students, seven faculty, and three postdoctoral fellows. The grant's purpose was to conduct interdisciplinary research to develop biodegradable, flexible electronics and promote high school students' awareness and interest in STEM and related career pathways, through science outreach activities. The STEM graduate students conducted research to develop biodegradable electronics and also served as STEM role models during outreach with the high school students. These activities included Zoom visits and field trips to campus to tour laboratories and meet with faculty and student researchers.

The current study focuses on the STEM graduate students' Zoom visits. The educational research team scheduled Zoom visits with the high school science teachers. The graduate students were asked to sign up for at least one of the requested visits, as a part of their commitment to the educational outreach, as it fit their schedules, and based on their desire to do so. One of the researchers, a postdoctoral fellow and the second author, met with the graduate students at least two weeks before each Zoom visit to review expectations and logistics, provide ideas for presentation topics, and address questions. During the planning meeting, the second author provided a planning document with guidance for the Zoom visit structure, such as discussing their research and its significance, conducting a tour of their laboratory, and discussing college and career experiences and advice (Table 1). However, the graduate students decided what they chose to present based on what they thought was most relevant to their research area and perceived as most important to share with the high school students.

5.2 Participants

Six international graduate STEM students (four females; two males; Table 2) and two domestic graduate STEM students (females) who were funded on the grant or who worked closely with one of the Principal Investigators were purposefully selected for this study (Patton, 2015) based on their participation in Zoom visits. The international graduate STEM students were from Europe, South and North America, and South and East Asia, and were science and engineering doctoral and master's students (three had dual enrollment in two graduate programs). The domestic graduate STEM students were enrolled in Biomaterials, Bioengineering, Chemical Engineering, Polymer Science, Mechanics Science, Data Analysis, Earth Science, Environmental Science, and Business (with a dual enrollment in an environmental graduate program). Four of the graduate students had long-term engagement with the grant, including attending monthly project team meetings (see Table 2).

The graduate STEM students' research was centered on sustainability, with a shared goal of developing a device that was flexible, with biodegradable and reusable components. Lily's research focused on using natural resources, such as trees, to produce sustainable biopolymer-based, flexible films that could be used in biodegradable electronics applications. Similar to Lily's research, Marcus' research project focused on developing and testing bio-based films using different substrates, such as agarose and chitin. Alan conducted research on semiconductors and sustainable electronics. Dora's research was aimed at refining printing techniques that would

TABLE 1 Summary of planning guidance that was provided to the STEM graduate students.

Suggested structure of the Zoom visit (20 min if 1 presenter; 10 min if 2 presenters)
• Goal: To conduct an interactive and engaging lab tour and college/career discussion with high school students. • Introduce yourself (name, program, how did you get here?) • Introduce your research (including its importance & impact) • Short lab tour (suggestion: pre-record short video clips & share screen)   ◦ Ideas: substrate examples; instruments; expensive equipment; software; safety/hazardous materials • You may also discuss careers/career outlook; your school/college experiences; tips/advice for students • Q&A
Tips and suggestions
• Avoid jargon (explain terms that students might not know) • Relate your research to big picture ideas (Why is it important? How will it help society?) • What has your journey been like to get where you are now? • What do you wish you would have known as a younger student? • It's okay to discuss challenges (e.g., in your research, in your college/career pathway) • Students usually like to know typical starting salaries and job opportunities

TABLE 2 Description of the participants and Zoom sessions.

Pseudonym	Country of origin	Program/research topic	Program partic. (sems.)	Information presented	Zoom visit details
Alan*	North American territory	Ph.D. Polymer Science/ Semiconductors and sustainable electronics	4	1. His daily life 2. His lab space (fume hood, purifying semiconductors) 3. Synthetic lab (rotary evaporator, microwave reactor, chemicals) 4. Device lab (glove boxes, 3D printers)	Zoom 1: 62 min (solo)
June	United States	Ph.D. Earth Science/Life-cycle analysis	2	1. Her science pathway 2. Carbon dioxide removal and enhanced weathering 3. Life cycle assessment	Zoom 1: 28 min (solo); Zoom 2: 19 min (solo)
Lily*	South American country	Ph.D. Biomaterials, Chemical Engineer/Bio-polymer based films	4	1. Her science pathway 2. Cellulose 3. Lab equipment (e.g., scanning electron microscope) 4. Salary for STEM degrees	Zoom 1: 51 min (duo); Zoom 2: 34 min (duo) Zoom 3: 34 min (solo)
Selena	United States	Master's Environmental and Master's Business/Impact investing	2	1. Her science pathway 2. Plastics 3. Sustainability, environmental impact	Zoom 1: 60 min (solo); Zoom 2: 20 min (solo)
Marcus*	South Asian country	Ph.D. Bioengineering/Bio-based films	4	1. His science pathway 2. Sustainability and eco-friendly materials (chitosan, agarose, chitin) 3. Soft, flexible electronic devices 4. Lab equipment and techniques 5. Salary for STEM degrees	Zoom 1: 51 min (duo); Zoom 2: 53 min (duo)
Hailey	East Asian country	Ph.D. Environmental and Master's Data Analysis/Life cycle analysis	1	1. Life cycle assessment 2. Salary for engineers and data scientists 3. Daily life as a graduate STEM student	Zoom 1: 52 min (duo)
Tamara	European country	Master's Earth Science/Life cycle analysis	2	1. Her science pathway 2. Trash, sustainability 3. STEM careers and salary	Zoom 1: 66 min (duo); Zoom 2: 22 min (solo)
Dora*	South Asian country	Ph.D. Mechanics Science/ Printable, flexible sensors	1	1. Her science pathway 2. Nanomaterials, flexible sensors 3. Applications of sensors	Zoom 1: 32 min (solo)

Program partic. (sems.) means participation in program in semesters. *Denotes graduate students who participated in monthly grant meetings and facilitated sessions during high school field trips to a research university campus and project laboratories, in addition to the Zoom visits.

allow flexible sensors to be printed on biodegradable, wearable films. June, Tamara, Selena, and Hailey were part of the same lab group that studied sustainability using non-laboratory-based methods. June, Tamara, and Hailey performed computer-based modeling and life cycle assessment to investigate challenges such as carbon dioxide removal and waste management. Selena's work was at the intersection of business and sustainability, known as impact investing.

5.3 Planning and implementing Zoom visits

The Zoom visit was pre-planned by the graduate students, who were supported by grant staff to think through what they might present to high school students in a science classroom. For instance, the graduate students were encouraged to conduct an "interesting and engaging" visit, to avoid lecture, consider their own educational pathway, and explain why their research was important to society. However, graduate students made their own decisions of what and how to present their backgrounds and research, whether to make a pre-recorded video to share, and whether to Zoom in from their lab setting or office. During their Zoom visits, seven graduate students shared about their personal life and academic pathway, eight students showed their laboratory and discussed their sustainability-related research, and three students included details about STEM careers and salaries.

Implementation was either one graduate student (solo) or two graduate students (duo) for each Zoom visit. When working with the graduate students to prepare, the postdoctoral fellow let them know whether there would be one or two graduate students presenting, so they would know how much time they had. Students had approximately twenty minutes to present if presenting alone (solo), followed by questions. If two students presented (duo), they each had 10 minutes to present, followed by a shared question portion. However, the classes were scheduled for a 90-minute block, and some of the Zoom sessions lasted as much as 65 minutes (see Table 2). For graduate students who volunteered to present multiple times, their presentations seemed to repeat what they had initially done, with minor changes on what they actually said and the questions that students asked them.

5.4 Data collection and analysis

For this case study, the data sources included Zoom classroom visits and semi-structured individual interviews. There were 11 Zoom classroom visits (eight solo visits and three duo visits), which lasted between 20 and 65 minutes, each. Six visits were conducted in the Fall and five during the Spring. Each Zoom visit was conducted with a different high school science class. For each Zoom visit, one or more education graduate students also logged in to start, record, and facilitate the Zoom session. Four graduate STEM students each participated in two separate Zoom visits, and one graduate student participated in three visits. This was all of the graduate students' first opportunity to present their research to high school students. Researchers' reflective notes were useful in remembering some of the details of the planning sessions.

Seven semi-structured interviews were conducted to understand how the graduate students planned and implemented the high school Zoom visits, what they believed was the purpose of the visit, and what goals and outcomes they anticipated achieving as a result of their visit (Gill et al., 2008; Mertens, 2019). Interviews were conducted following each graduate student's Zoom visit. All interviews had at least two interviewers present and lasted an average of 20 minutes. One international female graduate STEM student joined the grant later and conducted the Zoom visit but declined an interview.

Audio recorded data was transcribed verbatim, resulting in thirty single-spaced pages of interview transcripts and 116 single-spaced pages of Zoom visit transcripts for analysis (with slight clean-up of words such as "uh," "like," and "umm"). Due to the exploratory nature of this case study, the data were inductively analyzed using the constant comparative method (Glaser and Strauss, 1999). Guided by Strauss and Corbin (1998), first, open coding was conducted, in which data were separated into discrete segments, carefully analyzed, and similarities and differences were identified. A set of codes was identified. Next, higher order grouping of codes into categories was completed. A codebook that contained all codes and categories with their description and inclusion and exclusion criteria was created by the first author. The inductive codes and thematic analysis were used to form the findings for the first two research questions. To address the third research question, the three key role model functions, behavioral models, representations of the possible, and inspirations, were applied as deductive codes. Each of the categories from the thematic analysis was categorized under a primary role modeling function in order to understand how the graduate students may have exemplified the three role model functions.

5.5 Trustworthiness

The first author independently coded the interview and Zoom visit transcripts (codes are detailed in Tables 3 and 4 in the Findings). Interrater reliability was established between the first two authors using a unitization approach with 23% of the data (Campbell et al., 2013). The first two authors discussed the codes together to align their interpretations. Next, copies of the transcripts were shared with the second author, keeping the segments highlighted but removing the codes so that the second author could use the codebook to independently code the segmented data. Initial simple agreement was calculated (86%), and all disagreements were discussed and negotiated until 100% agreement was achieved (Patton, 2015).

Member checking was also conducted to ensure the researchers' interpretations accurately represented participants' experiences and voices. To perform member checking, the researchers created a summary for each Zoom visit and interview (one to two pages each) and shared the summary documents with each graduate student for their review and feedback. Five of the eight participants reviewed and approved the summaries, offering few or no corrections. Three graduate students did not provide a response. Additionally, rich descriptions and quotes from participants were included to help the reader judge the findings and enhance trustworthiness.

5.6 Positionality

The first author is a high school science/mathematics teacher who has worked in low-income communities for 18 years. She is also a part-time international graduate student. She has experienced the unfamiliarity of a different culture and language and navigated additional challenges in these roles. This insider status (Merriam, 2001) lent insight into understanding the pedagogical decisions and some of the experiences described by the participants. Several strategies were employed to mitigate potential biases, such as constantly and critically examining the interpretations of the data, peer debriefing with coauthors, and acknowledging that having similar history and experiences as the participants does not mean they are the same as the researcher's.

6 Findings

6.1 How graduate STEM students planned and implemented their Zoom visits

To address the first research question and understand how graduate STEM students planned for and implemented their Zoom visits, data from both the Zoom classroom visits and the reflective interviews were analyzed. The graduate STEM students described three key factors that guided their planning and implementation: (1) engaging students, (2) relevance of science to society, and (3) opportunities for jobs in science (see Table 3). These three themes were found in the majority (82.3%) of all of the coded statements and were more prevalent in the Zoom visits than in the interviews.

For instance, from the total number of statements coded as 'engaging students,' approximately 83% were found in the Zoom visits as the

TABLE 3 Description of themes and subthemes related to planning and implementing the Zoom visits.

Theme and subthemes	Percent	Example quote from Zoom visit (Z) or interview (I)
1. Engaging students		
Younger selves and prior academic experiences	30.3%	"I feel like in, when I was in high school, it's like, you are either a doctor or you are a lawyer or a teacher like those are the 3 jobs that exist in the world… those [other sustainability jobs] kind of… help expand some … horizons." (Selena, I)
Everyday, relatable science concepts and processes	20.2%	"We work with them to help them understand like how they could rework their packaging to not use single use plastic…My project mates were in the lab growing a mycelium mold that would hold the printer cartridge …, and that way you would not need… a conventional plastic." (Selena, Z)
Fun, interesting, or inspiring facts	9.6%	"All time you are learning new things. In my work, I'm never bored, never. I never have a chance to be bored." (Lily, Z)
2. Relevance of science to society		
Relevance of science to society	11.5%	"And so the idea of enhanced weathering that lots of companies and governments are starting to look at is, could we, as a population, basically grind up a lot of rock and put it on agricultural land. And… basically take significant amounts of carbon out of the atmosphere." (June, Z) "My research is actually something that you can…connect it with normal things like trees, you know… Actually, trees are made from polymers. They are different from oil…The bottle of water comes from petroleum, but the paper comes from trees." (Lily, I)
3. Opportunities for jobs in science		
Careers in science	9.2%	"So there's another type of career called data scientists…every industry might need data scientists." (Hailey, Z)
Science stereotypes	1.5%	"I have a picture of coffee here because I love coffee. The first thing which I do in the morning is my having my coffee with some homemade banana bread … Then, obviously, I need to have a work life balance. I usually go to the gym and then do some kind of outdoor activities." (Dora, Z)
Total	82.3% of all coded statements	

The percentages were calculated from the total number of coded statements.

TABLE 4 Description of themes and subthemes related to supports, benefits, and challenges.

Theme and subthemes	Percent	Example quote from Zoom visit (Z) or interview (I)
Supports and benefits		
Supports and benefits	10.5%	"I was impressed [by]… the quality of the questions…I thought that they [the students] asked generally pretty good questions." (Selena, I) "I really like this opportunity to talk about my work and like to motivate other people." (Marcus, Z) "The professors [teachers] did a great [job of] … repeating and trying to catch the [students'] question." (Lily, I)
Challenges		
Challenges of being a scientist in the classroom	5.1%	"So I was worried that I might use, like too many jargon words, or something that they will find it very difficult to understand." (Marcus, I)
Challenges of being an international student	2.3%	"English is not my first language. I have, like good days with English, and like no very, very good days with English." (Lily, I) "I saw that there was 2 people in the front like joking each other, I think, because of my accent, especially when I use the word pounds instead of dollars." (Tamara, I)
Total	17.9% of all coded statements	

The percentages were calculated from the total number of coded statements. Due to rounding of percentages, the total of coded statements from Tables 3 and 4 is slightly different from 100%.

graduate students actively engaged the high school students, and 17% were found in the interviews, when the participants reflected on how they thought about engaging the students. Similarly, for the 'relevance of science to society' theme, 90% of the coded statements came from the Zoom visits and 10% from the interviews. Of the statements coded as 'opportunities of jobs in science,' 86% were found in Zoom visits, when students described career opportunities, and 14% in interviews, when they described their thinking about how to include information about job opportunities.

6.1.1 Engaging students

Engaging students was the most pervasive consideration expressed by graduate students when planning and implementing the Zoom visits, present in all of the graduate students' Zoom visits and interviews, and constituting 60.1% of all of the coded statements. The graduate students used three strategies to engage students: talking about their younger selves and prior academic experiences from high school and graduate programs (30.3%); including every day, relatable science concepts and processes

(20.2%); and including fun, interesting, and inspiring examples in their presentations (9.6%).

The most common strategy the graduate students used to engage the high school students was sharing about their *younger selves and prior academic experiences* as former high school, undergraduate or graduate students. This strategy was found in six interviews and all Zoom visits. For example, Marcus, during his interview, projected himself back in time as a high school student: "It reminded me of myself. So at that time, I think I did not really have any clear idea of, like what the students do during their highest study, like for doing research." Similar to Marcus, Lily thought about her high school experience:

> I really like to encourage people to reconsider science, because I know science are challenging during high school. It was in my case, even though I enjoy the science, they were challenging in many way. So I try to put in like the idea of, 'Okay, it's difficult, but it's worth it' (Lily, interview).

During a Zoom visit, Selena thought of engaging the students by sharing some of her childhood experiences with them: "I am from a low-income neighborhood often seen in movies for its gang violence … So when I was thinking about where I wanted to go to college, I, you know, like to be far away from home." She shared with the high school students how she had always dreamed of becoming a doctor and how, after going into hospitals, she realized that being a doctor was not her dream anymore. Then, she explained how she decided to enroll in the graduate program at [Southern State University]:

> I think this is like very silly, but I think [Southern State University] was the first college that I've ever heard of when I was in the fourth grade … and so, my friends and I, we all made a pact. We said, we're all going to go to different middle schools. We're all going to reunite at [Southern State University] (Selena, Zoom visit).

Dora, during a Zoom visit, shared her science pathway and explained how she started her undergraduate studies in engineering but then switched to another science field, even though she did not know anything about the new field and wasn't sure about the change. Dora emphasized to the high school students that there are many opportunities to engage with STEM:

> So the main takeaway is, even if you're not sure about which major you want to go to, don't be too worried because these days everybody is doing highly interdisciplinary work … Everything is multi-disciplinary. So don't be worried because the opportunities are endless, and it's never too late too, even after you work. And if you want to go back to research, you can do that (Dora, Zoom visit).

The second most common strategy the graduate students used to engage the high school students was including *everyday, relatable science concepts or processes* in their presentations. This strategy was found in five out of seven interviews and in all Zoom presentations. Lily introduced biopolymers by connecting to cellulose and then to trees: "Cellulose is the most abundant biopolymer, and it comes from … trees. You know. We all know trees very well" (Lily, Zoom visit).

Marcus, during a Zoom visit, referred to the end life of common electronic devices that high school students use:

> What happens to these devices or cameras … when you are done using them? You just throw it away, right? … Some get recycled, so where do they end up eventually? They eventually end up in the environment and like, create some mess like this, right? … this is very bad for [the] environment … So we need to find the solution to how to tackle this situation (Marcus, Zoom visit).

Hailey discussed life cycle analysis, likely a completely unfamiliar concept for high school students, in connection to plants, energy and the environment:

> So the lab that I previously was in, we are using the biomass, like plants, to do some very advanced materials. But while doing the experiments, I figured that I'm actually wasting lots of chemicals, and also consuming a lot of electricity. So, I'm just curious that while I am saying that I'm producing … something that is renewable, and also very environmentally friendly, but I'm not sure if it's really environmentally friendly. So, I want to use a life cycle assessment tool to really assess those products to see whether it's really environmentally friendly or not (Hailey, Zoom visit).

The third strategy graduate students used to engage the high school students was the inclusion of *fun, interesting, or inspiring examples* in their presentations, which was found in all interviews and nine out of 11 Zoom visits. Marcus emphasized that he enjoys doing research, constantly learning, and creating materials with different properties: "So I personally, I really enjoy doing research. It's … really fun, … I'm always learning new things, … I'm doing new stuff, … inventing new stuff is … very cool …" (Marcus, Zoom visit). Similarly, Lily said: "In my opinion, all time you are learning new things. You're never bored, believe me, when you are a scientist" (Lily, Zoom visit).

In her interview, Lily said that she wanted to "inspire curiosity" during one of the Zoom presentations by presenting her safety equipment in a funny way: "So I'm wearing the same [clothes] that Mr. Lizard wears in this picture: lab coat, glasses, gloves, long pants, and closed shoes" (Lily, Zoom visit). Selena hoped to inspire students to pursue further education: "Maybe they already all are planning to apply to college, but I hope they seriously consider it … and I hope that they … have confidence in themselves that they can do whatever it is they want to do (Selena, interview).

Some graduate students discussed examples of salaries in science fields to engage students. Marcus said, "So if you are doing undergrad, and hopefully, maybe when you guys graduate you'll be able to get around … $140,000 per year. Which is pretty good" (Marcus, Zoom visit). Lily talked about salary as one type of motivation for working in STEM: "I know some of my mates have found work that pay more than $100,000 per year. They found work very quickly …, even before graduation … But that's not my motivation. My motivation is science. Obviously, the payment is an extra motivation" (Lily, Zoom visit).

6.1.2 Relevance of science to society

Relevance of science to society was the second most important consideration, which was included in all participants' presentations and reflected 11.5% of all coded statements from Zoom presentations and interviews. Graduate students gave examples of science applications that everyone in society uses, such as paper: "Paper is everywhere, but it's cheap … Maybe they [high school students] could not understand how important is paper in society" (Lily, interview). Tamara, during one of the Zoom visits, talked about waste, recycling, and how city councils design their trash collecting systems, emphasizing the relevance of science in everyday life:

> Everyone [city councils, companies, local residents] wants to know, 'Well how much of my plastic waste is actually being recycled, and how much of that waste actually makes it back into a new bottle, like what's useful? Does recycling even work?'… It [trash] is really important from an environmental perspective, because landfills have caused environmental harm. You know, they take up space on the land, and they can release harmful chemicals through leaching, but more so than that, the materials that we currently put into landfall could be used again, and if we put a material, say a plastic bottle in the landfill, to produce a new plastic bottle we need to extract more material from the earth … If we could reduce that plastic… we could reduce the environmental impact of the products that we use" (Tamara, Zoom visit).

6.1.3 Opportunities for jobs in science

The third factor considered when planning the classroom visit was *opportunities for jobs in science*, reflecting 10.7% of all coded statements. The majority of these (86%) focused on *careers in science.* There are many unfamiliar STEM jobs that high school students do not know about, as Tamara noted in her interview: "I do not think anyone thinks about trash as a career… there is a big workforce that works in waste management…there are loads of jobs out there that nobody knows what the job title is when they are in high school." During Zoom visits, Selena mentioned other possible jobs in science, such as working for "some cool companies that take plastic out of the ocean and make them into different products" and that the "government uses science to make decisions and to make research agendas." During Zoom visits, June also explained the importance of jobs related to carbon dioxide removal in the current context of global warming:

> Carbon dioxide removal. That's a subject that's now … being promoted a lot by government, … new startup companies … and even a lot of companies … that are already established, like technology companies or transportation companies like airlines, are really interested in carbon dioxide removal from the perspective of offsetting their emissions" (June, Zoom visit).

A few of the graduate STEM students considered debunking *scientist stereotypes* as a factor when planning and presenting Zoom visits. This theme was not prevalent across all data sources, and it was not explicitly discussed during the planning meeting or included in the planning document; it appeared in one interview and four Zoom visits. Alan, in his interview, stated: "Since I was a child, they have portrayed these people [scientists] as … having glasses, only talking about the science, and not really having hobbies or anything like that. Just being lab rats. I feel like breaking that stereotype." Going further, Alan pointed out that those with science careers live normal lives: "I also want to say that I do way more things than just doing science. So, I play soccer. I played varsity soccer in my undergraduate institution. I'm also a fiancé, and my favorite holiday is Halloween" (Alan, Zoom visit).

Hailey, during a Zoom visit, positioned herself as a person who has fun with her friends: "…these are my lovely labmates … So, we will sometimes attend conferences together, and sometimes just have fun together, maybe like hiking, or just hang out." Similarly, Selena wanted to present herself as a person who lives a normal life, and she introduced the high school students to her dog at the beginning of one Zoom visit.

6.2 Supports, benefits, and challenges experienced by graduate STEM students

In relation to the second research question, the themes of support, benefits, and challenges were found in 17.9% of all the coded statements (see Table 4) and are described in detail in the following sections.

6.2.1 Support and benefits experienced by graduate STEM students

The support and benefits theme was reflected in 10.5% of all coded statements and appeared in all interviews and in five out of eleven Zoom visits. The *support* the graduate STEM students received came from the university team members and the high school teachers. Tamara received support from the high school teacher, saying, "I think in some cases the teacher reworded the questions for me, maybe like knowing what they meant, and then know what I would understand. So, [I] thought the teacher was important" (Tamara, interview).

The university team members provided support on how to plan the presentation and provided a list of possible topics to be addressed during the presentation. June stated that she planned her presentation based on a conversation with one of the educational research team members: "I had talked to [Author 2] and kind of separated it to try to be 30% about sort of my background and experience getting to my program. And then … 70 … percent talking about my research area" (June, interview). Reflecting on the Zoom presentation, Lily commented on a support that would have been helpful leading up to the visit: "Maybe a little rehearsal with you [researcher] would be nice like, you to point me out that, 'Please go this way,' because I'm not used to explain these complex things to non-academic people" (Lily, interview). Although the second author held a preliminary planning meeting with each graduate student, additional meetings or feedback on their presentations leading up to the visits were optional, and Lily's comment suggests that more could have been helpful.

A few graduate STEM students mentioned the *benefits* they experienced from their participation. Marcus said, "It was a good opportunity for me to interact with these high school students" (Marcus, interview). Alan noted another benefit of the Zoom visits was the ability to reach students who otherwise might have difficulty interacting with scientists due to the distant and rural location of some high schools. Alan experienced benefits of being a scientist in the classroom and felt his time with the high school students was valued:

> I actually felt very good about what I did… I feel like … the students making the amount of questions that they did, I feel like I did a fairly good job of engaging with them … So having

> students to ask questions was … I was very, very happy … I think it went well. I felt comfortable at all times … with both talking to the students and teacher. I think it was a very good environment as well … It made me very happy to have as much questions because it made me feel that they enjoyed the presentation, and felt I identified in some type of way … and I felt like they respected my time there (Alan, interview).

Marcus also noted that the high school students were interested in his research and asked questions that demonstrated their curiosity: "They seemed … very interested about our research …, they were … very intuitive. They were asking me some creative questions" (Marcus, interview). Similarly, Hailey said: "I think they [high school students] asked good questions, and also they are kind of pretty engaged in the discussions" (Hailey, interview). Also, Hailey noted high school students' interest in her as a researcher and a person, and not only in her research: "I was a bit surprised that people will actually be interested in [laugh] why I get into that [life cycle assessment] and… not just [asking about] professional salaries or things like that… (Hailey, interview).

6.2.2 Challenges experienced by graduate STEM students

Challenges the graduate students encountered were evident in 7.4% of all coded statements and were associated with being a scientist in the classroom and being an international student. This theme came up in all graduate students' interviews and two out of eleven Zoom visits. All seven participants who were interviewed mentioned the *challenge of being a scientist in the classroom*. Lily found it difficult to talk about and show pre-recorded videos of her research without using the very specialized technical language of her field. She found it challenging to make complex academic language understandable to high school students:

> It was challenging, since it's difficult to … not use like complex terms, or explain like in deep the research … It's not that easy to explain to teenagers what I'm doing. It's like when I try to explain to my mother. You know, my mother is no scientist, so she suffered to try to understand what I'm doing (Lily, interview).

During one of the Zoom visits, when presenting pre-recorded videos of her labs, Lily reassured students that what they will see and hear might be too technical, but that is normal, "and you do not need to understand everything there."

Selena, when asked what she would change about her presentation, said that her words might not have been "accessible" to the high school students and that she would choose her "words more carefully" because:

> …sometimes using overly complicated language, can create a barrier to like, connecting with people … I think if I were watching that in high school I'd be like, oh, I'm totally intimidated, and this is like too much for me… I would try to use … I guess, eleventh grade language to the extent that I remember what that is (Selena, interview).

June experienced similar challenges when planning her presentation. She wanted to present her "area of research in a way that was digestible," and she chose very carefully what to share by considering "what material is just kind of not relevant to a group of high schoolers" (June, interview). The educational research team anticipated the challenge of conveying complex, discipline-specific research ideas to high school students in a short amount of time. They encouraged the STEM graduate students to "avoid jargon," explain concepts on a level that students could understand, and focus on broader themes instead of technical details.

The *challenge of being an international student* surfaced from the interviews of two female students, Tamara and Lily. Being an international student brings the challenge of a different culture, as Tamara pointed out: "Some of their [high school students'] questions … were not what I would expect back home … I think [there were] two questions. One was about how much you earn, and the other one was like return on investment, which, from my perspective, [were] very American questions" (Tamara, interview).

Lily, reflecting back on the Zoom presentation and her English skills, said that she would "try to speak slow … because I'm trying to improve my pronunciation, to deliver exactly the idea that I want… [so] people understand me better" (Lily, interview). During one Zoom visit, Lily shared with the high school students that even though she is a foreigner, and "this [English] is not my first language, …my career gives me the opportunity to learn another language." Figure 2 provides a summary of the factors the graduate students considered most when planning and implementing the Zoom visits and the supports, benefits, and challenges they perceived.

6.3 Mapping graduate students' Zoom visits and reflections onto the Motivational Theory of Role Modeling

The third research question sought to connect the findings from the Zoom visits and interview reflections to the Motivational Theory of Role Modeling. To do so, the three key role model functions, *behavioral models, representations of the possible*, and *inspirations*, were used as deductive codes. Each of the subthemes from the thematic analysis was categorized under a primary role modeling function. These findings are described in the following sections, and displayed in Figure 3.

6.3.1 Behavioral models

The graduate STEM students acted as *behavioral models* by sharing information about their younger selves and prior academic experiences, and sharing fun, interesting facts. These were detailed in the thematic analyses (6.1.1) as ways that the role models engaged students. Through the Zoom visits, the graduate students showed the high school students "how to do something" (Morgenroth et al., 2015, p. 471), such as how to conduct research, by presenting their research topics, research processes, laboratory techniques, and lab equipment to the high school students. These interactions aimed to demonstrate scientific practices and convey what it is like to be a scientist to the younger students. Additionally, by sharing fun, interesting facts and examples, the graduate students demonstrated dispositions and attitudes of scientists and researchers.

Another way the graduate STEM students positioned themselves as *behavioral models* was by sharing their high school or undergraduate experiences and steps they took to pursue STEM in higher education and

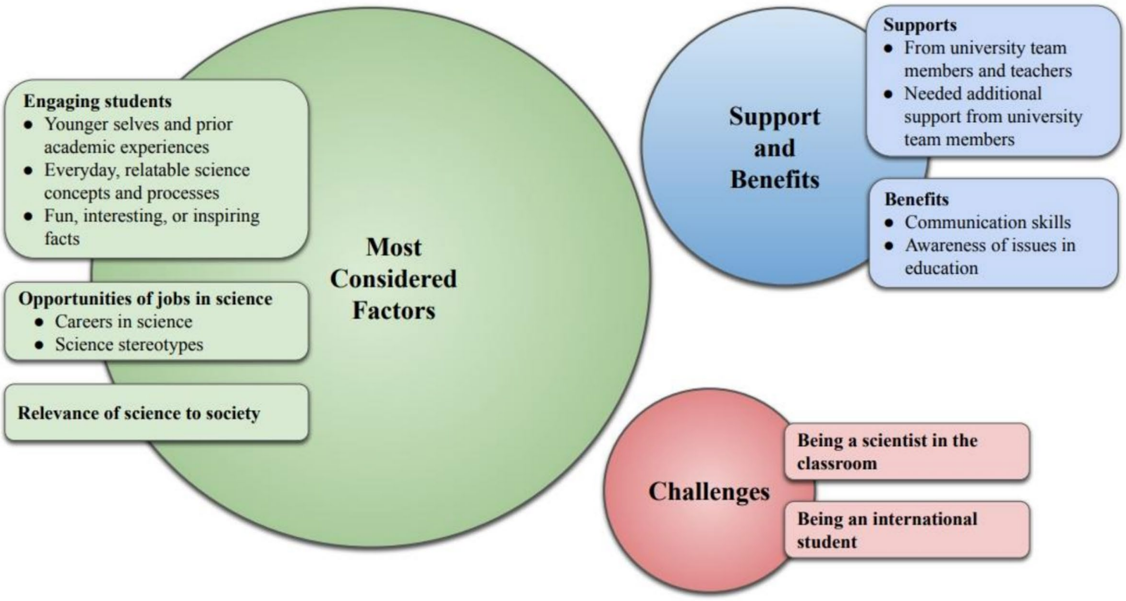

FIGURE 2
Factors the participants considered most and the perceived supports, benefits, and challenges for Zoom visits.

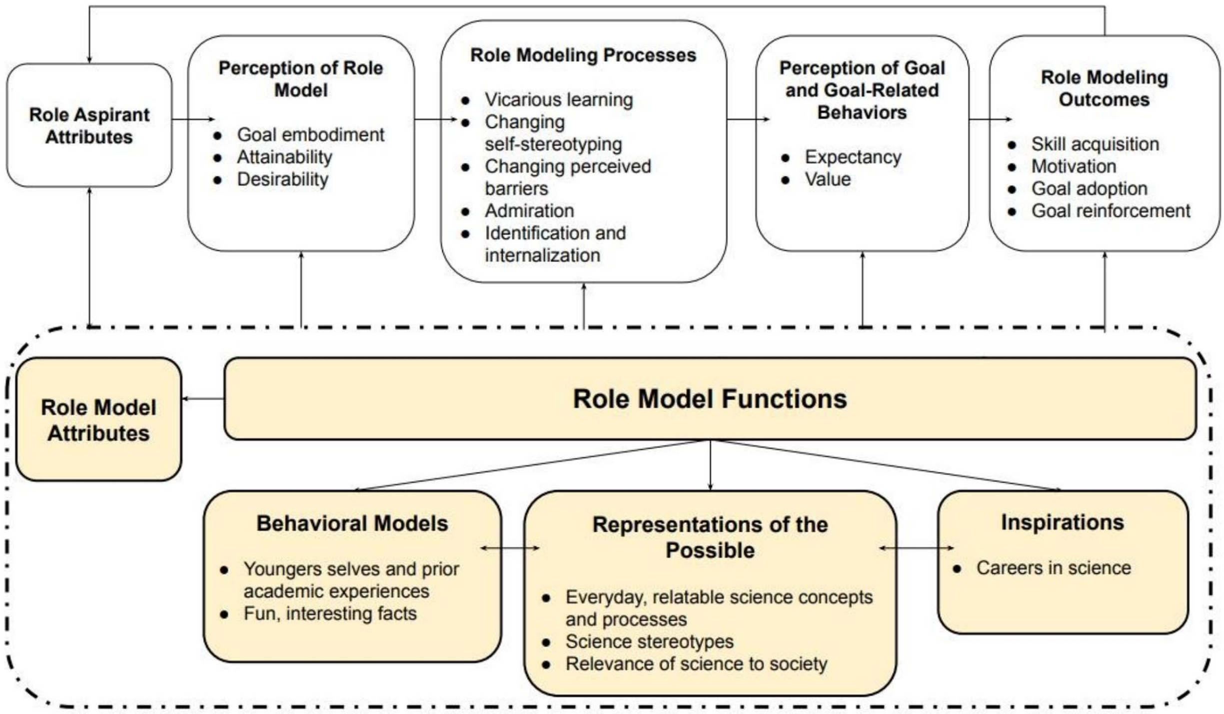

FIGURE 3
Overview of the Motivational Theory of Role Modeling (Morgenroth et al., 2015), highlighting the current study's contribution to the role models and their functions in yellow (within dashed border).

in their science career pathways. They attempted to relate to the high school students by acknowledging how science was difficult for them in high school while others recognized how they did not understand why they had to study topics like differentials and integration (calculus) in high school mathematics courses. Other graduate students acted as behavioral models and sought to engage students by unveiling stories of their personal experiences or motivations to pursue STEM and how their academic journeys led them toward their STEM career goals.

6.3.2 Representations of the possible

The graduate STEM students in this study *represented the possible* by sharing the relevance of science to society, including everyday, relatable science concepts, and challenging science stereotypes. These elements, described in sections 6.1.1 through 6.1.3, aimed to show the high school students that science is within reach (Morgenroth et al., 2015) through relevant examples of science in their Zoom presentations. The graduate students discussed how science had clear real-world applications and was used to benefit society and communities, hoping to expand students' perceptions of who is capable of being a scientist and what can be accomplished through science. When using examples for the relevance of science to society, the graduate students positioned themselves as role models by showing that doing science and contributing to the scientific endeavor were attainable and evident in phenomena that students already may be familiar with, such as recycling, biodegradability, and electronics.

Debunking scientist stereotypes was an important factor for a few of the graduate students. Role models *represented the possible* by addressing these stereotypes and potentially altering the way role aspirants made sense of the demographic structure of STEM careers (Morgenroth et al., 2015). The STEM graduate students challenged science stereotypes by sharing personal aspects of their identities during the Zoom visits, which they hoped could allow students to see similarities and feel a "shared social identity" with them, acting as a role model (p. 472). Some of the graduate students addressed scientist stereotypes by presenting themselves as people who live normal lives and do not only do science; they expressed how they established "a work life balance" by making time for personal interests like coffee, baking, sports, and outdoor activities.

6.3.3 Inspirations

Describing job opportunities in science aligned with the role model function of *being inspirational* by making STEM careers "desirable and worth striving for" and offering new career goals for students to consider (Morgenroth et al., 2015, p. 468). For example, during the Zoom visits, several of the graduate students talked about STEM jobs that were relevant to their unique area of study but may have been unfamiliar to the high school students. They discussed careers related to waste management, companies that recycle plastic from the ocean, green and sustainable energy technologies, and how the government uses science to make decisions and construct research agendas. To emphasize why these careers might be desirable and worth pursuing, the graduate students often spoke about having the potential to make the world a safer and more sustainable place through research. The graduate students attempted to inspire students by describing employment opportunities that the students may not have considered or been aware of prior to the Zoom visits and convey them in a way that students might perceive as exciting or impactful.

6.4 Summary

Three major themes emerged while students planned and implemented the Zoom sessions: graduate students predominantly focused on engaging students, demonstrating the relevance of science to society, and sharing about STEM job opportunities (Figure 2). The graduate students described the support and benefits that they received and/or would have liked to receive to prepare for and carry out the Zoom visits. They felt supported by the university team and the classroom teachers and that their communication skills and awareness of issues in education were enhanced through the experience. The graduate students expressed two types of challenges that comprised a small portion of coded statements in the interview data. These were related to being a scientist in the classroom and being an international student. Next, we mapped the subthemes reflected in the students' most considered factors onto the Motivational Theory of Role Modeling framework. This was to connect the findings from this study to the theory's key role model functions: serving as *behavioral models, representing the possible*, and *inspiring students*.

7 Limitations

The current study was carried out with a small group of graduate students, both international and domestic, who were part of one grant-funded project centered on the sustainable development of biodegradable, soft, and flexible electronics. Having other research goals may have led to other ways the graduate students thought to spark high school students' engagement and interest in STEM careers. Also, having a different sample of graduate students may have resulted in different findings. Data was limited to one interview and two Zoom visits for most of the graduate students, as a result of how many high school teachers requested a Zoom visit with a graduate student. Having additional Zoom classroom visits over time and multiple interviews with participants may have led to different findings. The findings will now be discussed, in light of these limitations.

8 Discussion

8.1 Planning and implementing the Zoom visits

The current study differs from previous research on STEM role models in that the high school students met and interacted directly with the graduate students on Zoom to learn about their research and STEM pathways. The international and domestic graduate STEM students in this study had advanced knowledge of their STEM field and sustainability-focused research, but none of them had prior experience presenting research to high school students. When planning and implementing the Zoom visits, the factors they most considered were engaging students, relevance of science to society, and job opportunities in science. The strategies the graduate students used to engage students were: (1) talking about their younger selves and prior academic experiences from high school, undergraduate, and graduate programs, (2) including everyday, relatable science concepts and processes, and (3) including fun, interesting, or inspiring examples in their presentations.

Engaging students was the most pervasive consideration expressed by graduate students, when planning and implementing the Zoom visits. A top strategy the graduate students used to engage high school students included sharing about themselves when they were younger. These findings resonate with those found by Alpert (2018), who stressed the importance of stimulating the enthusiasm and interest of the audience. By including relatable examples (Petchey et al., 2023) and reflections on their younger selves, the graduate students attempted to model to the high school students how to attain their goals, spark interest, and engage them. The graduate students presented "concrete steps that a student might take" (Gladstone and Cimpian, 2021, p. 12) to model how they arrived at their current roles in STEM, consistent with recommendations from Gladstone and Cimpian's systematic literature review of effective role models. An essential condition for understanding science is for students to be engaged (Hadzigeorgiou and Schulz, 2019), which the graduate STEM students in this study strove to do by presenting authentic research they conducted and talking about their experiences and lives. In other research, it was reported that when K-12 students are engaged in authentic science and perceive the graduate student scientists as friendly, "ideas about scientists, self-concept towards science, and level of science participation changed" (Conner and Danielson, 2016, p. 1). Although the high school students are beyond the scope of this study, the graduate students felt a high level of interest and participation by the students they met through their Zoom classroom visit.

The next most common strategy graduate students expressed was using examples that were relatable and might be commonly understood by the students. Communication with non-scientists (i.e., the high school students) has been emphasized as a fundamental skill required of scientists (NASEM, 2018), and one that has been found to be quite complex and challenging (Salita, 2015). This study addressed the call for graduate students to learn how to explain their research to a broader audience (NASEM, 2018), with institutional support that has been criticized as generally lacking (Brownell et al., 2013; Rose et al., 2020).

The third strategy graduate students used was including interesting, fun and inspiring examples in their presentations. These factors have not been the focus of prior scientist studies (Hanson et al., 2020; Laursen et al., 2007), and therefore, the findings in this study provide insight into how these graduate students approached their presentations. Other studies that focused on students' reactions to K-12 scientist outreach studies suggest that the graduate students' accessible approaches may have been beneficial to students' increased achievement and positive attitudes toward scientists (Taylor et al., 2022), increased awareness of ongoing scientific research (Clark et al., 2024; Clark et al., 2016) and perceptions of these scientists as attainable role models (Gartzia et al., 2021).

In their Zoom presentations and interviews, the *relevance of science to society* was the second most considered factor. Making science relevant to students has the potential to change how they perceive it. Siegel and Ranney (2013) found that students' beliefs about science relevance can be changed when they have exposure to real life science activities. Similarly, high school students' beliefs about the relevance of mathematics improved when using curriculum materials containing real-life examples (Gijsbers et al., 2020). In their Zoom visits, the graduate students talked about relevant science applications and emphasized that science is within reach and attainable, which is an important aspect of motivating high school students to pursue existing or new goals related to science careers (Gladstone and Cimpian, 2021; Morgenroth et al., 2015).

The third factor graduate students considered when planning the classroom visit was *opportunities of jobs in science*, which most often focused on careers in science, and, to a lesser extent, scientist stereotypes. Some graduate students talked about uncommon STEM careers and their salaries and outlook, with the intent to inspire and motivate the high school students to consider careers they may not have been aware of or considered prior to the Zoom visit. Habig et al. (2020) found that increasing students' STEM career awareness and persistence in STEM is provided by exposure to and repeated experiences with STEM professionals. In the case of this study, those STEM professionals were graduate students. Additionally, the exposure the high school students received in this study may have made them more aware and informed of opportunities in STEM. This type of exposure has been documented by Blotnicky et al. (2018) and Kitchen et al. (2024) as resulting in students being more likely to obtain careers in STEM.

8.2 Graduate STEM students' reflections on the Zoom visits

The graduate STEM students' reflections on how they planned and implemented the Zoom visits provide important insights to the design of professional development experiences for graduate students. Reflection is a critical component of effective professional development and improving one's instructional practice; however, it is not always integrated in professional development for graduate students (Di Benedetti et al., 2023). Additionally, reflection is a powerful component of learning; when someone intentionally thinks about what they did, it leads to better performance and increased learning (Di Stefano et al., 2014). Having the graduate students reflect on their Zoom visits and on their perceived support, benefits, and challenges, seems to have made them more aware of their experiences, which may improve their future teaching and communication skills as scientists in future interactions with lay audiences.

Numerous supports were revealed during the interviews. The graduate students recognized the support provided by the university team members as well as the classroom teachers. Faculty members are influential in helping international students successfully navigate graduate school (Antonio and Baek, 2021), and they can make students feel they are co-contributors to research and esteemed collaborators (Cantwell et al., 2018). Teachers providing classroom management support for graduate students who were acting as scientists in the classroom has been previously documented (Ufnar et al., 2017; Ufnar and Shepherd, 2021). In previous research, graduate students who participated in outreach efforts perceived benefits such as improved communication and career skills and became familiar with education issues (Kompella et al., 2020; Laursen et al., 2012; Ufnar et al., 2012), consistent with some of the benefits expressed by the graduate students in this study.

The graduate students described the challenge of being a scientist in the classroom while presenting complex and highly specialized research in a simplified way. This finding aligns with existing research that shows that scientists do not find it easy to communicate with lay audiences (Salita, 2015). Although the graduate students in our study cited this challenge, it is promising that their use of everyday, relatable science concepts and connections to the relevance of science to society were prominent in our findings, suggesting that, with support, they were able to communicate in a way that was relatable to students and seemed attainable (Bamberger, 2014; Gartzia et al., 2021; Gladstone and Cimpian, 2021). The international graduate STEM students also reported challenges related to English skills and cultural differences, consistent with research that most international graduate STEM students studying in the U.S. report cultural challenges (Han and Appelbaum, 2016) and challenges with English skills (Jiang, 2014; Rodriguez et al., 2024) when working with undergraduate students. Our findings add to the literature, as there is scant research that includes international graduate STEM students' experiences as scientists in the classroom, despite them representing a substantial portion of STEM graduates (NASEM, 2018; Smith et al., 2024).

The interviews contributed uniquely to our understanding of the graduate STEM students' planning and implementing of the Zoom visits. The codes were represented differently across the Zoom visits and the interviews. Engaging students, relevance of science to society, job opportunities in science, and science stereotypes were not as prevalent in the interviews as they were in the Zoom visits. The support, benefits, and challenges of being a scientist in the classroom and of being an international student were more common in the interviews and were rarely observed in the Zoom visits. These differences point out the advantages of both observing (and recording) live interactions of scientists with students and also interviewing them to learn more about the experience. The reflective aspect of the interviews revealed insights that may not have been garnered from the visits alone in terms of the support, benefits, and challenges that the graduate students experienced (Schön, 1983; Machost and Stains, 2023).

8.3 Role model functions

This study focused on the experiences of international and domestic graduate STEM students who positioned themselves as role models for high school students (Figure 3), rather than the focus taken by Morgenroth et al. (2015) on the role aspirants' perceptions of role models. The current study's adoption of the role model perspective is a novel application of the Motivational Theory of Role Modeling framework, providing insight into how the three role model functions (behavioral models, representations of the possible, and inspirations) were carried out, specifically within the graduate STEM student and K-12 outreach context.

This study offers a more nuanced conceptualization of the role modeling functions, for instance, by broadening the understanding of what it means to be a behavioral model. The findings revealed that the graduate students served as behavioral models not only in how they demonstrated their research processes and modeled behaviors of a research scientist, but also in how they modeled the steps along their journey and how they arrived at their current roles in STEM. These findings expand the interpretation of the framework and provide evidence for multiple types of behaviors that role models can display.

The framework acknowledges the "three functions are by no means independent of each other" and calls for additional evidence in various contexts (Morgenroth et al., 2015, p. 478). This study's findings demonstrate the potential overlap between the three role model functions. For instance, by sharing about their STEM journeys, the graduate students served as behavioral models and representations of the possible. Additionally, sharing the relevance of science and challenging scientist stereotypes represented the possible and may have inspired students who perceived the qualities to be desirable and relevant to their own goals and identity. By sharing about career opportunities, the graduate students served as both inspirations and also representations of the possible. The overlap of role model functions suggests the strategies the graduate STEM students employed during the Zoom visits engaged them in multiple role model functions at the same time. That is, in practice, they did not operate in discrete ways during role model interactions.

9 Conclusion

The current study makes a number of contributions. First, prior to this study, there were no published studies on how graduate students planned and implemented high school classroom visits through an online platform, as prior research on graduate students in K-12 classrooms focused on the benefits and outcomes of in-person activities. Therefore, this study builds off of prior research (Hinojosa, 2018) to reveal the graduate student role models' experience with students in a K-12 classroom. Second, informed by the literature (Lee, 2019; DeChenne et al., 2012), this study provides a practical model for how to provide professional development (Table 1) for graduate students to Zoom into K-12 classrooms to share their scientific research and also their educational pathways. Third, by including both international and domestic graduate students in the study, we are able to understand the experiences of a more representative sample of graduate students (NASEM, 2018; Smith et al., 2024). International students' cultural differences, reflected both in language challenges and different cultural norms, affected their experiences. These differences provided challenges as well as opportunities to learn more about American high school students. Finally, and perhaps most importantly, this study presents a novel extension of the role modeling framework (Morgenroth et al., 2015), by focusing on the role modeling by graduate STEM students rather than the experience of students who have role models.

10 Recommendations

Several recommendations for university STEM and Education departments result from our findings, with the intention of better supporting graduate STEM students who serve as role models. The recommendations were grouped in two sections: one focusing on providing professional development and support to graduate students involved in outreach activities, and one focusing on role models aspects.

10.1 Recommendations for graduate student professional development and support

1. Encourage graduate STEM students to participate in K-12 outreach activities as part of their appointment on grant-funded research projects.
2. Ensure that graduate STEM students have consistent support from at least one Education-focused team member during the

planning and implementation of the classroom visit, including a planning meeting and a practice session.
3. Design professional development for graduate STEM students that includes a reflection component to help them improve their communication and teaching skills and to consider what worked well and what could be improved.
4. Design science outreach programs with language and cultural aspects in mind to support international graduate students as STEM role models and highlight scientists with diverse identities.
5. Provide more formal or personalized support or training to international graduate STEM students to help build their English skills.
6. Incorporate more formalized, institutional training in communicating with lay audiences into graduate STEM programs or as professional development within grant-funded projects to bolster graduate students' skills and prepare them for scientist in the classroom roles and a variety of future careers.

10.2 Recommendations for role model outreach

1. Allow graduate students to decide how and what to present to students, based on what they perceive will engage students and convey the relevance of science to society.
2. Encourage the graduate students to provide information about a variety of STEM careers to make them seem desirable and to provide several possibilities.
3. Encourage graduate students to consider sharing their prior academic experiences and journey in STEM to show that STEM pathways and careers are attainable.
4. Encourage graduate students from underrepresented groups to participate in outreach activities, as a perceived similarity to the role models might encourage a diverse body of high school students to aspire to have STEM careers and resist scientist stereotypes.

Introducing students to scientists and engineers is often considered beneficial for the students, who have an opportunity to meet a professional, reconsider stereotypes, and consider their own potential in STEM career pathways (Conner and Danielson, 2016). Graduate students also benefit from role models in their own development (Conner and Danielson, 2016; Passi and Johnson, 2016). This study highlights some of the benefits the graduate students, while serving as role models, also received. Their reflection on these experiences helped them to realize and express those benefits as well as the challenges. This research expands the Morgenroth et al. (2015) Motivational Theory of Role Modeling by focusing on graduate STEM students, who served as role models. By following recommendations that draw from this study, professional development of graduate STEM students and outreach activities can be designed so scientists and engineers can enhance the broader impacts of their research and better position themselves as role models for the next generation of STEM professionals.

Data availability statement

The datasets presented in this article are not readily available for sharing due to the small sample of participants and qualitative nature of the study. Requests to access the datasets should be directed to katherine.mccance@utsa.edu.

Ethics statement

The studies involving humans were approved by Institutional Review Board (or Ethics Committee) of North Carolina State University (protocol 14030, 07-20-2018). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

A-MT: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. KM: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing. MB: Conceptualization, Funding acquisition, Methodology, Visualization, Writing – review & editing. JS: Data curation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was funded by the National Science Foundation (NSF) grant number 2134664.

Acknowledgments

We thank the graduate students for their interview and Zoom visit contributions and the high school teachers and students for their participation. We also thank the grant PI Dr. Yong Zhu, Co-PIs, and universities for their support and laboratory resources.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

References

AAAS (n.d.). Graduate STEM fellows in K-12 (GK-12) education program. Available online at: https://www.aaas.org/page/archives/graduate-stem-fellows-k-12-education-program (Accessed November 1, 2024).

Agrawal, A., and McNair, L. (2021). An intersectional analysis of the English-competency experiences of international teaching assistants. *J. Int. Stud.* 11, 950–969. doi: 10.32674/jis.v11i4.2343

Alpert, C. L. (2018). So you want to share your science … Connecting to the world of informal science learning. *Integr. Comp. Biol.* 58, 85–93. doi: 10.1093/icb/icy008

Alves, M., Alexander, M. M., Camara-Poot, V. M., and Ortega, M. E. (2015). Increasing the number of sponsored Mexican graduate students in engineering. Available online at: https://peer.asee.org/increasing-the-number-of-sponsored-mexican-graduate-students-in-engineering-2015 (Accessed November 1, 2024).

Antonio, A. L., and Baek, C. (2021). Beyond survey measures: exploring international male graduate students' sense of belonging in electrical engineering. *Stud. Grad. Postdoct. Educ.* 13, 132–150. doi: 10.1108/sgpe-02-2021-0015

Atkinson, M. P., and Slatta, R. W. (2021). "Mind the gap: a description of US doctoral education, challenges, and the skills gap" in The future of doctoral research: Challenges and opportunities. eds. A. Lee and R. Bongaardt (London: Routledge), 53–64.

Bamberger, Y. M. (2014). Encouraging girls into science and technology with feminine role model: does this work? *J. Sci. Educ. Technol.* 23, 549–561. doi: 10.1007/s10956-014-9487-7

Blotnicky, K. A., Franz-Odendaal, T., French, K., and Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *Int. J. STEM Educ.* 5, 22–15. doi: 10.1186/s40594-018-0118-3

Border, L. L., and Von Hoene, L. M. (2010). "Graduate and professional development programs" in A guide to faculty development. eds. K. J. Gillespie and D. L. Robertson (Hoboken, NJ: Jossey-Bass), 327–345.

Brownell, S. E., Price, J. V., and Steinman, L. (2013). Science communication to the general public: why we need to teach undergraduate and graduate students this skill as part of their formal scientific training. *J. Undergrad. Neurosci. Educ.* 12, E6–E10.

Campbell, J. L., Quincy, C., Osserman, J., and Pedersen, O. K. (2013). Coding in-depth semistructured interviews: problems of unitization and intercoder reliability and agreement. *Sociol. Methods Res.* 42, 294–320. doi: 10.1177/0049124113500475

Cantwell, B., Lee, J. J., and Mlambo, Y. (2018). International graduate student labor as mergers and acquisitions. *J. Int. Stud.* 8, 1483–1496. doi: 10.32674/jis.v8i4.211

Clark, G., Chai, W., Brightbill, C. M., and Rogers, K. (2024). Abstract 2444 middle school science educational outreach programs: shadow a scientist and present your Ph.D. thesis to a 12-year-old. *J. Biol. Chem.* 300:107114. doi: 10.1016/j.jbc.2024.107114

Clark, G., Russell, J., Enyeart, P., Gracia, B., Wessel, A., Jarmoskaite, I., et al. (2016). Science educational outreach programs that benefit students and scientists. *PLoS Biol.* 14:e1002368. doi: 10.1371/journal.pbio.1002368

Clarke, M. A., Sharma, N. M., and Schiller, N. (2019). An outreach program with hands-on, physiology-based exercises generates questions about STEM career expectations. *Adv. Physiol. Educ.* 43, 175–179. doi: 10.1152/advan.00013.2019

Conner, L. D. C., and Danielson, J. (2016). Scientist role models in the classroom: how important is gender matching? *Int. J. Sci. Educ.* 38, 2414–2430. doi: 10.1080/09500693.2016.1246780

De Gioannis, E., Pasin, G. L., and Squazzoni, F. (2023). Empowering women in STEM: a scoping review of interventions with role models. *Int. J. Sci. Educ.* 13, 261–275. doi: 10.1080/21548455.2022.2162832

DeChenne, S., Lesseig, K., Anderson, S. M., Li, S. L., Staus, N. L., and Barthel, C. (2012). Toward a measure of professional development for graduate student teaching assistants. *J. Effect. Teach.* 12, 4–19.

Di Benedetti, M., Plumb, S., and Beck, S. B. (2023). Effective use of peer teaching and self-reflection for the pedagogical training of graduate teaching assistants in engineering. *Eur. J. Eng. Educ.* 48, 59–74. doi: 10.1080/03043797.2022.2054313

Di Stefano, G., Gino, F., Pisano, G. P., and Staats, B. R. (2014). Learning by thinking: How reflection aids performance. Available online at: https://static1.squarespace.com/static/5015703ae4b00a22f5c94ed5/t/550ce6e6e4b083611f69fdce/1426908902699/feedback.pdf (Accessed November 1, 2024).

Fong, C. J., Gilmore, J., Pinder-Grover, T., and Hatcher, M. (2019). Examining the impact of four teaching development programmes for engineering teaching assistants. *J. Furth. High. Educ.* 43, 363–380. doi: 10.1080/0309877X.2017.1361517

Fried, T., and MacCleave, A. (2009). Influence of role models and mentors on female graduate students' choice of science as a career. *Alberta J. Educ. Res.* 55, 482–496. doi: 10.11575/ajer.v55i4.55341

Fry, R., Kennedy, B., and Funk, C. (2021). STEM jobs see uneven progress in increasing gender, racial and ethnic diversity. Pew Research Center. Available online at: https://www.pewresearch.org/science/wp-content/uploads/sites/16/2021/03/PS_2021.04.01_diversity-in-STEM_REPORT.pdf (Accessed November 1, 2024).

Ganapati, S., and Ritchie, T. S. (2021). Professional development and career-preparedness experiences of STEM Ph.D. students: gaps and avenues for improvement. *PLoS One* 16, e0260328–e0260325. doi: 10.1371/journal.pone.0260328

Gartzia, L., Ryan, M. K., and Peters, K. (2021). Testing the motivational effects of attainable role models: field and experimental evidence. *J Theoret Soc Psychol* 5, 591–602. doi: 10.1002/jts5.121

Gesing, P., and Glass, C. (2019). STEM student mobility intentions post-graduation and the role of reverse push-pull factors. *Int. J. Educ. Dev.* 65, 227–236. doi: 10.1016/j.ijedudev.2018.08.008

Gijsbers, D., de Putter-Smits, L., and Pepin, B. (2020). Changing students' beliefs about the relevance of mathematics in an advanced secondary mathematics class. *Int. J. Math. Educ. Sci. Technol.* 51, 87–102. doi: 10.1080/0020739X.2019.1682698

Gill, P., Stewart, K., Treasure, E., and Chadwick, B. (2008). Methods of data collection in qualitative research: interviews and focus groups. *Br. Dent. J.* 204, 291–295. doi: 10.1038/bdj.2008.192

Gladstone, J. R., and Cimpian, A. (2021). Which role models are effective for which students? A systematic review and four recommendations for maximizing the effectiveness of role models in STEM. *Int. J. STEM Educ.* 8, 59–20. doi: 10.1186/s40594-021-00315-x

Glaser, B., and Strauss, A. (1999). Discovery of grounded theory: Strategies for qualitative research. *1st* Edn. London: Routledge.

González-Pérez, S., Mateos de Cabo, R., and Sáinz, M. (2020). Girls in STEM: is it a female role-model thing? *Front. Psychol.* 11:2204. doi: 10.2139/ssrn.3541939

Habig, B., Gupta, P., Levine, B., and Adams, J. (2020). An informal science education program's impact on STEM major and STEM career outcomes. *Res. Sci. Educ.* 50, 1051–1074. doi: 10.1007/s11165-018-9722-y

Hadzigeorgiou, Y., and Schulz, R. M. (2019). Engaging students in science: the potential role of "narrative thinking" and romantic understanding. *Front. Educ.* 4:38. doi: 10.3389/feduc.2019.00038

Han, X., and Appelbaum, R. P. (2016). Will they stay or will they go? International STEM students are up for grabs. Ewing Marion Kauffman Foundation. Available online at: https://files.eric.ed.gov/fulltext/ED570660.pdf (Accessed November 1, 2024).

Hanson, L. M., Westerlund, J. F., and Vaughan, P. W. (2020). Gender differences in student attitudes towards science in secondary school classrooms with and without NSF GK-12 resident scientists. *Electr. J. Res. Sci. Math.* 24, 50–68.

Harshman, J. (2020). Review of the challenges that face doctoral education in chemistry. *J. Chem. Educ.* 98, 259–269. doi: 10.1021/acs.jchemed.0c00530

Heflinger, C. A., and Doykos, B. (2016). Paving the pathway: exploring student perceptions of professional development preparation in doctoral education. *Innov. High. Educ.* 41, 343–358. doi: 10.1007/s10755-016-9356-9

Hinojosa, L. (2018). "Encountering and becoming role models: combating underrepresentation in STEM" in 13th international conference of the learning sciences: Rethinking learning in the digital age: Making the learning sciences count. eds. J. Kay and R. Luckin (London, UK: International Society of the Learning Sciences), 120–127.

Jiang, X. (2014). Chinese biology teaching assistants' perception of their English proficiency: an exploratory case study. *Qual. Rep.* 19, 1–24. doi: 10.46743/2160-3715/2014.1226

Kitchen, J. A., Williams, M. S., Sonnert, G., and Sadler, P. (2024). A quasi-experimental study of the impact of college-run science, technology, engineering, and mathematics (STEM) career days on American students' STEM career aspirations. *Int. J. Sci. Educ.* 46, 109–130. doi: 10.1080/09500693.2023.2220071

Knippenberg, M. T., Leak, A., Disseler, S., and Segarra, V. A. (2020). Establishing partnerships for science outreach inside and outside the undergraduate classroom. *J. Microbiol. Biol. Educ.* 21:2025. doi: 10.1128/jmbe.v21i2.2025

Kompella, P., Gracia, B., LeBlanc, L., Engelman, S., Kulkarni, C., Desai, N., et al. (2020). Interactive youth science workshops benefit student participants and graduate student mentors. *PLoS Biol.* 18:e3000668. doi: 10.1371/journal.pbio.3000668

König, L. M., Altenmüller, M. S., Fick, J., Crusius, J., Genschow, O., and Sauerland, M. (2024). How to communicate science to the public? Recommendations for effective written communication derived from a systematic review: Zeitschrift für Psychologie. 233, 40–51. doi: 10.1027/2151-2604/a000572

Krutsch, E., and Roderick, V. (2022). STEM day: Explore growing careers. U.S. Department of Labor Blog. Available online at: https://blog.dol.gov/2022/11/04/stem-day-explore-growing-careers#:~:text=In%202021%2C%20there%20were%20nearlythe%20total%20for%20all%20occupations (Accessed November 1, 2024).

Laursen, S., Liston, C., Thiry, H., and Graf, J. (2007). What good is a scientist in the classroom? Participant outcomes and program design features for a short-duration science outreach intervention in K–12 classrooms. *CBE Life Sci. Educ.* 6, 49–64. doi: 10.1187/cbe.06-05-0165

Laursen, S. L., Thiry, H., and Liston, C. S. (2012). The impact of a university-based school science outreach program on graduate student participants' career paths and professional socialization. *J. High. Educ. Outreach Engag.* 16, 47–78.

Lee, S. W. (2019). The impact of a pedagogy course on the teaching beliefs of inexperienced graduate teaching assistants. *CBE Life Sci. Educ.* 18:ar5. doi: 10.1187/cbe.18-07-0137

Leshner, A. I., and Scherer, L. (2019). Critical steps toward modernizing graduate STEM education. *Issues Sci. Technol.* 35, 46–49. Available at: https://www.jstor.org/stable/26948989

Lim, J. H., Wang, Y., Wu, T., Li, Z., and Sun, T. (2021). Walking on gender tightrope with multiple marginalities: Asian international female students in STEM graduate programs. *J. Int. Stud.* 11, 647–665. doi: 10.32674/jis.v11i3.2132

Lockwood, P. (2006). "Someone like me can be successful": do college students need same-gender role models? *Psychol. Women Q.* 30, 36–46. doi: 10.1111/j.1471-6402.2006.00260.x

Love Stowell, S. M., Churcill, A. C., Hund, A. K., Kelsey, K. C., Redmond, M. D., Seiter, S. A., et al. (2015). Transforming graduate training in STEM education. *Bull. Ecol. Soc. Am.* 96, 317–323. doi: 10.1890/0012-9623-96.2.317

Machost, H., and Stains, M. (2023). Reflective practices in education: a primer for practitioners. *CBE Life Sci. Educ.* 22:2. doi: 10.1187/cbe.22-07-0148

McAlexander, S. L., Blanchard, M. R., and Venditti, R. A. (2024). Transfer students' perceptions of science and engineering internships. *Sustainability.* 16. doi: 10.3390/su16156429

McClure, M. B., Hall, K. C., Brooks, E. F., Allen, C. T., and Lyle, K. S. (2020). A pedagogical approach to science outreach. *PLoS Biol.* 18, 1–8. doi: 10.1371/journal.pbio.3000650

Merriam, S. B. (2001). Qualitative Research and Case Study Applications in Education. *2nd* Edn. San Francisco, CA: Jossey-Bass.

Mertens, D. (2019). Research and Evaluation in Education and Psychology: Integrating Diversity with Quantitative, Qualitative, and Mixed Methods. *5th* Edn. Cham: SAGE Publications.

Merton, R. K. (1957). Social theory and social structure. New York, NY: Free Press.

Moglen, D. (2017). International graduate students: social networks and language use. *J. Int. Stud.* 7, 22–37. doi: 10.32674/jis.v7i1.243

Morgenroth, T., Ryan, M. K., and Peters, K. (2015). The motivational theory of role modeling: how role models influence role aspirants' goals. *Rev. Gen. Psychol.* 19, 465–483. doi: 10.1037/gpr0000059

NASEM (2018). Graduate STEM education for the 21st century. Washington, DC: The National Academies Press.

NCSES (2017). Survey of doctorate recipients. Available online at: http://ncsesdata.nsf.gov/doctoratework/2017 (Accessed November 1, 2024).

NCSES (2023). Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023 (Special Report NSF 23–315). Available online at: https://ncses.nsf.gov/wmpd (Accessed November 1, 2024).

Nguyen, D. J., and Yao, C. W. (Eds.) (2022). A handbook for supporting Today's graduate students. *1st* Edn. New York, NY: Taylor & Francis.

NSF (2008). NSF 101: Five tips for your broader impacts statement. NSF 101: five tips for your broader impacts statement. Available online at: https://new.nsf.gov/science-matters/nsf-101-five-tips-your-broader-impacts-statement (Accessed November 1, 2024).

NSF (n.d.). NSF graduate teaching fellows in K-12 education (GK-12). Available online at: https://new.nsf.gov/funding/opportunities/nsf-graduate-teaching-fellows-k-12-education-gk-12/5472/nsf08-556/solicitation (Accessed November 1, 2024).

Ozturgut, O. (2013). Best practices in recruiting and retaining international students in the U.S. *Curr. Issues Educ.* 16:22.

Passi, V., and Johnson, N. (2016). The impact of positive doctor role modeling. *Med. Teach.* 38, 1139–1145. doi: 10.3109/0142159X.2016.1170780

Patton, M. Q. (2015). Qualitative Research & Evaluation Methods: Integrating theory and practice. *4th* Edn. Thousand Oaks, CA: Sage Publications, Inc.

Petchey, S., Treagust, D., and Niebert, K. (2023). Improving university life science instruction with analogies: insights from a course for graduate teaching assistants. *CBE Life Sci. Educ.* 22:ar24. doi: 10.1187/cbe.22-07-0142

Philip, T. M., and Azevedo, F. S. (2017). Everyday science learning and equity: mapping the contested terrain. *Sci. Educ.* 101, 526–532. doi: 10.1002/sce.21286

Pringle, R. M., Lord, C. G., and Sheppard, T. D. (2020). "Secondary STEM learning" in Handbook of research on STEM education. eds. C. C. Johnson, M. J. Mohr-Schroeder and T. J. Moore (New York, NY: Taylor and Francis Group), 115–127.

Rodriguez, M., Roman, B. Z., Mohamed, M., and Barthelemy, R. (2024). Social and cultural barriers reported by STEM international graduate students of color. *J. Int. Stud.* 14, 276–302. doi: 10.32674/jis.v14i3.6694

Rose, K. M., Markowitz, E. M., and Brossard, D. (2020). Scientists' incentives and attitudes toward public communication. *Proc. Natl. Acad. Sci.* 117, 1274–1276. doi: 10.1073/pnas.1916740117

Ruiz, N. G. (2014). The geography of foreign students in U.S. Higher Education: Origins and Destinations. Available online at: https://www.brookings.edu/wp-content/uploads/2014/08/Foreign_Students_Final.pdf (Accessed November 1, 2024).

Salita, J. T. (2015). Writing for lay audiences: a challenge for scientists. *Med. Writ.* 24, 183–189. doi: 10.1179/2047480615z.000000000320

Schön, D. A. (1983). The reflective practitioner: How professionals think in action. New York, NY: Basic Books.

Shin, J. E., Levy, S. R., and London, B. (2016). Effects of role model exposure on STEM and non-STEM student engagement. *J. Appl. Soc. Psychol.* 46, 410–427. doi: 10.1111/jasp.12371

Siegel, M. A., and Ranney, M. A. (2013). Developing the changes in attitude about the relevance of science (CARS) questionnaire and assessing two high school science classes. *J. Res. Sci. Teach.* 40, 757–775. doi: 10.1002/tea.10110

Smith, B., Alldredge, E., Arbeit, C. A., and Yamaner, M. I. (2024). Graduate enrollment in science, engineering, and health continues to increase among foreign nationals, while postdoctoral appointment trends vary across fields NSF 24-320. Alexandria, VA: National Center for Science and Engineering Statistics.

Strauss, A., and Corbin, J. M. (1998). Basics of qualitative research. *3rd* Edn. Thousand Oaks, CA: Sage.

Taylor, J., Adams, C. T., Westbrook, A. L., Gee, J. C., Skybook, J. K., Kowalski, S. M., et al. (2022). The effect of a student– teacher–scientist partnership program on high school students' science achievement and attitudes about scientists. *J. Res. Sci. Teach.* 59, 423–457. doi: 10.1002/tea.21733

Ufnar, J. A., Bolger, M., and Shepherd, V. L. (2017). A retrospective study of a scientist in the classroom partnership program. *J. High. Educ. Outreach Engag.* 21, 69–96.

Ufnar, J. A., Kuner, S., and Shepherd, V. L. (2012). Moving beyond GK–12. CBE—life sciences. *Education* 11, 239–247. doi: 10.1187/cbe.11-12-0119

Ufnar, J. A., and Shepherd, V. L. (2021). The sustained scientist in the classroom partnership: a model for innovative STEM graduate training programs. *J. STEM Outreach* 4:11. doi: 10.15695/jstem/v4i1.11

Vennix, J., den Brok, P., and Taconis, R. (2016). Perceptions of STEM-based outreach learning activities in secondary education. *Learn. Environ. Res.* 20, 21–46. doi: 10.1007/s10984-016-9217-6

Vennix, J., den Brok, P., and Taconis, R. (2023). Motivation style of K–12 students attending outreach activities in the STEM field: a person-based approach. *Learn. Environ. Res.* 26, 129–143. doi: 10.1007/s10984-022-09407-z

Wan, T., Geraets, A. A., Doty, C. M., Saitta, E. K., and Chini, J. J. (2020). Characterizing science graduate teaching assistants' instructional practices in reformed laboratories and tutorials. *Int. J. STEM Educ.* 7:30. doi: 10.1186/s40594-020-00229-0