Received 20 February 2023
Revised 31 July 2023
25 August 2023
Accepted 21 September 2023

Supporting STEM graduate students in strengthening their professional identity through an authentic interdisciplinary partnership

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Abstract

Purpose – Historically, graduate education's goal was to prepare academics; now most science, technology, engineering and/or mathematics (STEM) graduate students (GSs) go on to nonacademic careers. STEM GSs must be equipped for success regardless of career aspirations, which can be done by strengthening GSs' professional identities. This study aims to explore an interdisciplinary partnership designed to strengthen STEM GS professional identity.

Design/methodology/approach – The STEM Partnership Project (SPP), asked STEM GSs to serve as disciplinary experts and teach STEM content to elementary teacher candidates (TCs) so the TCs could design and teach an elementary science lesson. GSs also enrolled in a one-credit course to support SPP participation and activities. Over five semesters, the authors collected data from 28 STEM GSs across different disciplines and degree programs in the form of course assignments, surveys and interviews.

Findings – The SPP supported the development of a professional identity by having GSs serve as and feel like experts; increasing GSs' sense of belonging in their field; increasing GSs' self-confidence that they could (learn to) teach a wide variety of audiences; and raising GSs' awareness of their ability to serve others via their field.

Originality/value – The SPP's outcomes were consistent across STEM disciplines, did not require GSs to take on large amounts of coursework, nor did it cost much beyond materials for the various lessons. Furthermore, the key components that strengthened GSs' professional identities could be adapted for different contexts and institutions.

Keywords Professional identity, STEM, Graduate education, Interdisciplinary partnerships

Paper type Research paper

Studies in Graduate and Postdoctoral Education
Vol. 15 No. 1, 2024
pp. 96-116

2398-4686
DOI 10.1108/SGPE-02-2023-0017

The authors wish to thank Donna Llewellyn for her thoughtful guidance and collaboration on this project.

This material is based upon work supported by the National Science Foundation under Grant No. 1806698.

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Introduction

Historically, graduate education's goal was to prepare future academics/scholars and it has thus focused on creating and conserving disciplinary knowledge (Matthews *et al.*, 2022; Porter and Phelps, 2014; Golde, 2006). However, the reality today is that most science, technology, engineering and/or mathematics (STEM) graduate students (GSs) go on to nonacademic careers (National Academies of Science, Engineering, and Medicine [NASEM], 2018; Denecke *et al.*, 2017). As educators, we should equip STEM GSs for success, regardless of career aspirations – particularly as the STEM graduate population continues to grow (National Science Board, and National Science Foundation, 2022).

In 1990, Boyer stated that:

> [. . .]graduate study must be broadened, encompassing not only research, but integration, application, and teaching, too. It is this vision that will assure, we believe, a new generation of scholars, one that is more intellectually vibrant and more responsive to society's shifting needs. (pp. 73–74)

In other words, Boyer argued that graduate programs must prepare students to use their expertise in a number of ways beyond the "traditional" notion of simply preparing more academic researchers. More than three decades later, calls continue for graduate programs that go beyond preparing students for academia (Cassuto and Weisbuch, 2021; Leshner, 2018). It is high time to finally heed this call and be purposeful about creating opportunities for (STEM) GSs to develop a strong professional identity in their field that extends beyond academia so they may apply their expertise to a variety of careers to meet the needs of society.

We argue that by historically centering graduate education around careers in academia and scholarship, developing and/or strengthening GSs' professional identities for a broader notion of what it means to be a STEM professional has been largely missing from STEM graduate education (Hancock and Walsh, 2016; Walker *et al.*, 2008). Consequently, we created the STEM Partnership Project (SPP), with the aim of using Boyer's (1990) suggestions of integration, application and teaching to support STEM GSs in creating a strong professional identity. The SPP engaged STEM GSs in an authentic interdisciplinary partnership: teaching disciplinary content to elementary teacher candidates (TCs) so the TCs could design and teach a rigorous elementary science lesson. We include the descriptor of "authentic" in this partnership to indicate that the SPP had real-world outcomes in terms of the TCs *needing* the content knowledge that would be transformed into a science lesson for *real elementary students*. The following research question guided our investigation of the SPP: *In what ways (if at all) does the SPP strengthen GSs' professional identities?*

Literature review

This research is guided by literature related to challenges in STEM graduate education and socialization during graduate school.

Challenges in science, technology, engineering and/or mathematics graduate education

In 2020, over 170,000 STEM graduate degrees were conferred in the USA [U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), 2021]. Although it is difficult to track attrition rates (NASEM, 2018; Berdanier *et al.*, 2020), it is typically estimated that around 40% of students who begin STEM graduate programs in the USA do not finish (Council of Graduate Schools, 2008; Xu, 2014). In essence, these 2020 graduates may have begun their programs with 113,000 additional colleagues who did not finish their programs, which is a staggering number. There are myriad reasons why students leave graduate programs and not all are within the control of institutions of higher

education. However, of those reasons that institutions can impact, the most commonly mentioned include minimal or poor relationships with faculty members such as advisors, lack of socialization with peers and/or department, an absence of connections of their work with the "real world" and personal meaning and unclear relationships between work in their program and multiple possible careers (Berdanier *et al.*, 2020; CGS and Educational Testing Service [ETS], 2010; O'Meara and Jaeger, 2006; Satterfield *et al.*, 2018).

Furthermore, racial and gender imbalances in enrollment and persistence are widespread in STEM fields (NASEM, 2018; CGS, 2016; Xu, 2014). Students from populations typically underrepresented in STEM (e.g. Black, Indigenous, Latinx people, and women) are less likely to enter these disciplines and if they do, are less likely to graduate (Charleston and Leon, 2016; Wilkins-Yel *et al.*, 2022; Xu, 2014). Black, Indigenous and Latinx people make up approximately 37% of the US population and yet only 24% of the STEM master's degrees and 16% of the STEM doctoral degrees earned by US citizens in 2021 were earned by people of color [National Center for Science and Engineering Statistics (NCSES), 2023]. This may be because while in their degree programs, Black, Indigenous and Latinx students in STEM often encounter feelings of isolation; racial stereotyping, bias and overt or covert racism; and being positioned as or feeling like an impostor. In addition, students of color may not have advisors/mentors who share and/or understand their racial identities, so that they can provide the support these students need to be successful in STEM programs (McGee, 2021). Women are making gains in the USA in terms of earning advanced degrees in STEM. However, in 2020, women were still significantly underrepresented in graduate STEM degrees in the USA, particularly in physical, earth and computational sciences, as well as in math and engineering. For example, women earned only 27% of the master's degrees and 25% of the doctoral degrees conferred to US citizens in engineering in 2020 (NCSES, 2023). Like the challenges encountered by people of color, women in STEM graduate programs may also encounter feelings of isolation; gender stereotyping, bias and overt or covert sexism; lack of female mentorship; and being positioned as or feeling like an impostor (Cheryan *et al.*, 2015; Sankar *et al.*, 2015; Shapiro and Sax, 2011).

Collectively, these challenges indicate a need for STEM graduate programs that allow GSs to build meaningful relationships with faculty and peers, participate in authentic applications of their expertise and consider multiple career options beyond academia.

Socialization in graduate education

Golde (1998) noted that, "The socialization of graduate students is an unusual double socialization. New students are simultaneously directly socialized into the role of graduate student and are given preparatory socialization into a profession" (p. 56). Golde goes on to say that there are four key tasks of GS socialization: intellectual mastery of content related to the field; learning about life as a GS; learning about the profession the GS wishes to pursue; and, integrating themselves into the department or program. Successful socialization into a graduate program and its respective field has been shown to be an important factor in degree persistence (Gardner, 2008; Russell *et al.*, 2016). During socialization, GSs acquire general and specialized knowledge, become invested in their area of specialization and adopt values, skills and roles associated with their profession and/or discipline (O'Meara, 2008; Weidman *et al.*, 2001). This third component is central to professional identity development as it allows others to witness their performance and validate their identity (Weidman *et al.*, 2001; Mantai, 2017). To be clear, graduate education can, indeed, support the creation of a professional identity, but due to the typical focus on preparing students for a life in academia, the vision of a professional identity in a particular field is often quite narrow. For example, Gardner (2008) proposed that not "fitting the mold" of a "young, White, single, male" (p. 126) – not coincidentally the typical vision of an academic – in graduate school may be a significant factor in GSs from populations typically

underrepresented in (STEM) graduate education leaving their programs. Consequently, it is important that socialization considers the ways in which individuals experience graduate school differently and may have different goals after graduate school.

Theoretical framework: professional identity

As GSs progress in their education, they create their professional identity. Tan *et al.* (2017) define professional identity as "[. . .]the self that has been developed with the commitment to perform competently and legitimately in the context of the profession[. . .]A person with such [identity] identifies with the profession, its role and values" (p. 1505). Professional identity is not divorced from one's other identities (Trede *et al.*, 2012), as characteristics such as age, gender and race significantly impact how individuals interact with the world (Nyström, 2009; Carlone and Johnson, 2007). Consequently, a professional identity can be thought of as an intersection "between personal resources, attitudes and values on the one hand, and work processes and settings on the other" (Kirpal, 2004, p. 201). McGee (2021) argues that for Black, Indigenous and Latinx people, it is particularly important that there is an integration between their personal values and their work if they are to persist in STEM.

Because GSs are pursuing a specialized degree, professional identity and disciplinary identity (e.g. a physics identity) are inextricably linked (Hazari *et al.*, 2010). Components of disciplinary identity are *competences*, such as content knowledge or knowledge of experimental processes; *performances*, such as the correct usage of tools and the ability to speak fluently with other STEM professionals; and *recognition* that is both internal ("I am a STEM professional!") and external (others seeing one as a STEM professional; Carlone and Johnson, 2007). Taken together, professional identity formation within a discipline – that is, seeing oneself and being seen as a STEM professional – requires one to learn the competences and performances related to that discipline, the discipline's role in society, and how to use one's expertise in a meaningful way. It has been argued that for STEM professionals, professional identity formation largely occurs during graduate school (Brownell and Tanner, 2012). Beyond graduate school, having a strong professional identity can support a sense of belonging within a professional group, which can positively impact self-perception, career decisions, confidence and mental health (Kunrath *et al.*, 2020).

Unfortunately, during their graduate career, GSs may experience impostor phenomenon, feel disconnected from their colleagues, lack motivation, struggle with academic achievement, feel anxious or lost or feel they do not belong in their discipline (Jensen and Jetten, 2015; Mantai, 2017; Noonan, 2015), all of which can contribute to attrition (Gardner, 2009). However, developing a professional/disciplinary identity combats these issues and promotes persistence, both at school and more generally in achieving professional goals (Hazari *et al.*, 2010; Sturtevant and Wheeler, 2019). This may be because the development of a professional identity creates a vision of a "future self" that can motivate students and provide meaning to their studies. However, it should be noted that possible future selves are not simply envisioned through students' efforts and actions, but also through others' (or society's) notions of what might be appropriate and/or feasible for them (Jensen and Jetten, 2015; Wyatt *et al.*, 2021). Consequently, it becomes vital to provide a variety of models and images of what a "future self" in a particular field could be – particularly because notions of future selves can change over time (Jensen and Jetten, 2015; Nyström, 2009). Programs can strengthen GSs' professional identities and share several future-self possibilities by providing opportunities for GSs to consider their values, explicitly discuss with GSs the importance of their field to society (Trede *et al.*, 2012), have opportunities to "perform" their disciplinary competence for others to be recognized as a professional in a particular field (Carlone and Johnson, 2007) and participate in communities of practice (Tomlinson and Jackson, 2021).

Intervention

Pilot implementations of the SPP happened in 2016 through 2018, with meaningful changes made in each iteration to best support GSs (Wenner and Simmonds, 2017). Beginning in Spring 2019, we implemented the SPP in its current form (with some changes for COVID-19; see Table 1 for detail) for five consecutive academic year semesters. The SPP was strategically designed to meet challenges related to STEM graduate education through an authentic interdisciplinary partnership intended to strengthen GSs' professional identities (Figure 1). In particular, we sought to build a community among the GSs and between the GSs and the authors, as well as provide a setting in which the GSs could apply their expertise to a real-world need of supporting elementary science instruction.

To help GSs in the SPP develop their understanding of pedagogy and issues related to educational environments, they were supported by the project faculty and a one-credit graduate college course (GCOLL course). Typical course topics include growth vs fixed mindsets, impostor phenomenon, novice to expert transitions and active learning (a full listing of course topics appears in Supplementary Material). GSs also read about the 5E Instructional Model (Bybee *et al.*, 2006) – a pedagogical framework for inquiry-based teaching typically used in science – and participated in a 5E lesson led by the first author (a science teacher educator). GSs reflected on their readings and experiences to make connections to ideas they could implement in their own work and future careers.

Within the GCOLL course, each GS constructed one 30-min, adult-level 5E lesson based on specific topics related to K-6 Next Generation Science Standards (NGSS; NGSS Lead States, 2013). The GSs then met with small groups of elementary TCs to teach their 5E lesson. GSs then met with the TCs twice more to serve as disciplinary experts as the TCs transformed the content into 15-min lessons for elementary students. To bring the SPP full

Semester	Alterations to original SPP model
Spring 2020	• GSs and TCs met once in person for GS 5E lesson (all courses moved online in March) • GSs and TCs did not meet further, but GSs provided online feedback to TCs' minilesson plans • TCs did not teach their minilesson due to upheavals in K-12 schools
Fall 2020	• GSs and TCs met twice via Zoom: GSs taught their 5E lesson; TCs asked questions and discussed minilesson ideas • Students from two elementary schools attended evening "home science enrichment" workshops via Zoom; each TC group taught a different workshop. Workshop attendance varied: some had only one child; the largest had five children. GSs attended these workshops via Zoom
Spring 2021	• GSs and TCs met twice via Zoom: GSs taught their 5E lesson; TCs asked questions and discussed minilesson ideas • We partnered with a public online school to teach three different sixth grade classes (15–20 students each) via Google Meet. Each class was split into three smaller groups that rotated through three lessons taught by the TCs. GSs attended these lessons via Google Meet

Table 1. Alterations to the SPP in response to COVID-19 restrictions

Note: Note that from the Spring 2020 semester onward, we made alterations to some SPP activities due to the COVID-19 pandemic (see Table 1)
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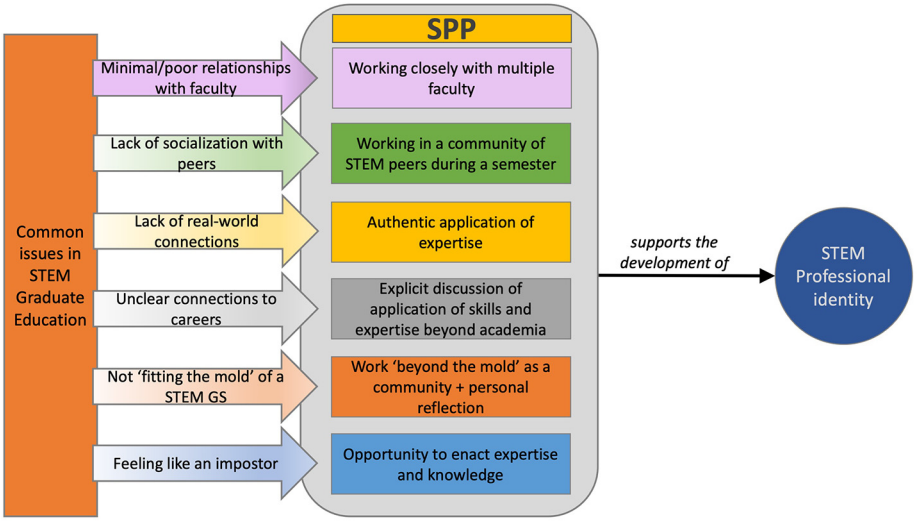

Source: Created by authors

Figure 1.
Mechanism for SPP supporting professional STEM identity

circle, GSs observed the TCs teaching the lessons to groups of local elementary students and reflected on the entire experience. Throughout the SPP, GSs had ongoing opportunities to work closely with the first and second authors on issues related to pedagogy and the GCOLL course, as well as with a content-area liaison, a faculty member from their home department (e.g. geosciences and physics) who could advise on issues related to STEM content. Figure 2 summarizes the SPP timeline.

Methods

The present study was undertaken as a single case study. Yin (2018) notes that case studies are appropriate when investigating a phenomenon (or "case") in depth and in its authentic context. In this study, enactment and outcomes of the SPP serve as the "case." Case studies benefit from prior theoretical propositions – such as strategically designing the SPP to support GSs and strengthen their professional identities – and rely on multiple data sources to triangulate findings (Yin, 2018). More details on the study can be found below.

Setting

This study took place at a university in the USA in which approximately one-eighth of the student population are GSs. The university offers 14 STEM master's degree programs and 8 of the 13 doctoral degree programs offered at the university are in STEM fields.

Participants

Over five semesters, we recruited 31 STEM GSs from degree programs in biology, physics, engineering and geology, as these best align with the NGSS content areas (NGSS Lead States, 2013). Recruitment happened indirectly: the authors attended departmental faculty meetings, shared information about the SPP and encouraged faculty members to support participation among their GSs. We also partnered with one faculty member in each

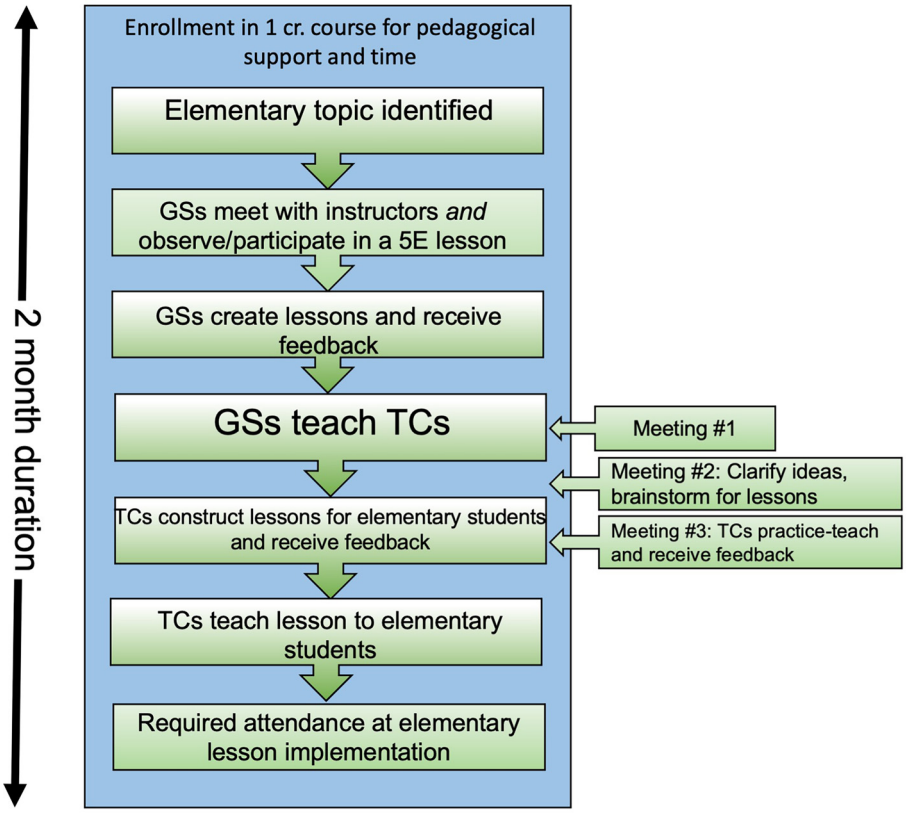

Figure 2.
SPP components and timeline

Source: Created by authors

department to liaise between the GSs/department and the SPP. The SPP was open to all GSs in these participating departments and GSs volunteered for the SPP. Of the 31 GSs who volunteered to participate in the SPP, 28 GSs consented to our study. Table 2 provides more detail concerning SPP participants. It should also be noted that there were two international students who participated in the SPP, but this is not indicated in Table 2 to protect their identities.

Data collection

Course assignments. All GS participants completed four assignments within the GCOLL course that we used as data: three pedagogy exploration reflections (Refl.1, Refl.2 and Refl.3) on their meetings with the TCs and course readings and an end-of-semester reflection (Refl. End).

Follow-up surveys. In Spring 2022, we sent out a follow-up survey (Survey) to all past SPP participants. This survey included 11 open-ended questions about perceptions of their professional identity, their discipline, teaching opportunities and potential impacts on their careers. Seventeen GSs completed this survey, spanning all five semesters of the SPP. Note

Table 2.
SPP participants

Semester	Pseudonyms	Graduate program	Graduate degree	Self-reported gender	Self-reported race/ethnicity	First generation college student (Y/N)	Career plans
Spring 2019	Anna Bert Charlie Daniel	Materials science and/or engineering = 4	Masters = 3 Doctorate = 1	F = 1 M = 3	White = 4 Two or more races = 0 Asian = 0 Black = 0 Hispanic/Latinx = 1	Y = 1 N = 3	Academia = 0 Gov't agency = 1 Industry = 3 Undecided = 0
Fall 2019	Eleanor Fiona Gemma Hattie	Biology = 4	Masters = 2 Doctorate = 2	F = 4 M = 0	White = 4 Two or more races = 0 Asian = 0 Black = 0 Hispanic/Latinx = 0	Y = 0 N = 4	Academia = 1 Gov't agency = 0 Industry = 0 Undecided = 3
Spring 2020	Ivan John Kevin Lionel Max Naomi Oscar	Chemistry = 1 Materials science and/or engineering = 5 Mathematics = 1	Masters = 4 Doctorate = 3	F = 1 M = 6	White = 3 Two or more races = 1 Asian = 2 Black = 1 Hispanic/Latinx = 1	Y = 0 N = 7	Academia = 1 Gov't agency = 2 Industry = 2 Undecided = 2
Fall 2020	Penelope Quentin Robert Suzanne Tina Ursula Violet	Biology = 3 Geosciences = 4	Masters = 3 Doctorate = 4	F = 5 M = 2	White = 5 Two or more races = 1 Asian = 0 Black = 1 Hispanic/Latinx = 1	Y = 3 N = 4	Academia = 2 Gov't agency = 1 Industry = 0 Undecided = 4
Spring 2021	Willow Xavier Zack Adelaide Beatrix Caroline	Materials science and/or engineering = 6	Masters = 3 Doctorate = 3	F = 4 M = 2	White = 4 Two or more races = 0 Asian = 1 Black = 1 Hispanic/Latinx = 0	Y = 2 N = 4	Academia = 0 Gov't agency = 0 Industry = 3 Undecided = 1 Unknown = 2

(*continued*)

Table 2.

Semester	Pseudonyms	Graduate program	Graduate degree	Self-reported gender	Self-reported race/ethnicity	First generation college student (Y/N)	Career plans
TOTALS	$n = 28$	Biology = 7 Chemistry = 1 Geosciences = 4 Materials science and engineering = 15 Mathematics = 1	Masters = 15 Doctorate = 13	F = 15 M = 13	White = 20 Two or more races = 2 Asian = 3 Black = 3 Hispanic/Latinx = 3	Y = 6 N = 22	Academia = 4 Gov't agency = 4 Industry = 8 Undecided = 10 Unknown = 2

Source: Created by authors

that due to the small sample size, we did not use existing quantitative STEM identity measures (Chemers *et al.*, 2010; Tan *et al.*, 2017) as we felt qualitative data (open-ended questions) would provide more insight into the GSs' experiences.

Interviews. At the end of each semester, we invited GSs to participate in a 20-min, semi-structured interview (Int.; Roulston, 2010) focused on themes of their experiences in the SPP, the GCOLL course and their interactions with the TCs. Twenty-one GSs participated in an interview; the interviews were recorded and transcribed verbatim. All assignments, surveys and interview protocols are available as Supplementary Materials.

Data analysis

All data sources were coded simultaneously and in no particular order (i.e. we did not code all of Anna's data and then all of Bert's data, nor did we code all interviews and then move to course assignments). This decision was made so that we might examine the SPP outcomes holistically as a "case." We completed several cycles of coding. First, each author read through all data for five participants individually and created emergent codes (Saldaña, 2021) relating to professional identity. From these, all authors agreed upon a set of codes and definitions. In the second cycle of coding, each author applied these codes to all data for another three participants. All authors then met to discuss coding difficulties (e.g. unclear boundaries between codes) and edited the set of codes. We repeated this second cycle of coding with three more participants and met again to clarify codes (see Supplementary Materials for our codebook). For the fourth and final cycle of coding, we divided the corpus of data such that each datum would be coded by two authors. Throughout each coding cycle, coding discrepancies and questions were discussed by all authors to reach agreement. After coding, each author wrote a memo about patterns they noticed, how these patterns aligned with professional identity (Saldaña, 2021).

All authors then met to discuss their memos and how the patterns that arose from coding might coalesce into broader themes. We returned to our definition of professional identity formation within a discipline, which includes seeing oneself and being seen as a STEM professional, possessing field-specific knowledge and skills, performing skills and ways of being aligned with the field, acknowledging the field's role in society and considering how to use field-specific expertise in a meaningful way. We found it was often difficult to parse out each of these components individually for the GSs in this study. For example, when a GS recognized that they were, indeed, a content-knowledge expert, this finding touched on internal recognition (I am an expert!), external recognition (Others see me as an expert!) and an acknowledgement of the competences they had (I know X, Y and Z advanced topics in my field). Consequently, our discussion of our memos allowed us to see nuances within the codes and craft themes that captured the complexity of professional identity within the data (see Figure 3).

The first theme, "I am an expert," combined ideas that were found in excerpts coded as "Awareness of expertise" and "I am a scientist," with components of external and internal recognition as well as acknowledgement of their competence. The second theme, "I feel like I belong" arose from excerpts coded as "Finding a fit in the field," "I can contribute," "Camaraderie with SPP GSs" and joyful aspects of "I am a scientist." This theme emphasized external recognition and performances that allowed GSs to feel as though they had "found their people." Although the SPP was not a program focused on teaching GSs how to teach, the third theme, "I can (learn to) teach" surfaced time and again in excerpts coded specifically for "How I should go about teaching," as well as excerpts coded for "I can contribute." This theme combines performances and newfound competences in teaching that might allow them to share their knowledge and expertise. Finally, the fourth theme, "I

have a duty to serve," emerged from excerpts coded explicitly as "Duty to serve," as well as excerpts coded as "I can contribute," and "Volunteering on behalf of the field." This theme tied together a better understanding of the field's role in society as well as their responsibilities to use their knowledge and expertise in a way that will benefit others.

Quality measures. We undertook multiple strategies to ensure the quality of this study. Cian (2021) notes that there are many ways in which researchers may address trustworthiness, rigor and/or credibility in a qualitative study, including components for Creswell and Miller's (2000) framework for validity in qualitative research as well as Messick's (1995) framework for validity as applied to qualitative studies. This study spans five semesters (prolonged engagement), is grounded in theory (professional identity) and sought triangulation as well as disconfirming evidence throughout the data collection and analysis phases. Furthermore, in our methodology and results, we present thick, rich descriptions so the reader may assess for themselves the degree to which our results may be generalizable.

Results

Collectively, the data indicates that the SPP supported the strengthening of a professional identity in terms of each component. It is worth noting that many SPP participants have identities that align with populations typically marginalized in STEM (Black, Indigenous, Latinx, female, first-generation college students). Nearly one-third of our participants identified as people of color; more than half of our participants identified as female; and almost one-quarter of our participants stated that they were first-generation college students. The findings did not appear to vary by demographic characteristic, which is encouraging given the challenges students from these populations can face in STEM graduate education.

I am an expert

All 28 GSs commented on an increased sense of expertise resulting from the SPP. There were three different yet related perspectives on this increased sense of expertise. First, 11 GSs noted that it can be difficult to acknowledge or see their expertise due to their role as students. Nonetheless, in the SPP, we intentionally chose to call the GSs "experts," which some, like Fiona, struggled with: "At first it was a little bit weird [to be referred to as an expert] because I think as a graduate student, I spend most of my time feeling like I don't know nearly enough about my discipline" (Int.). Penelope agreed with this sentiment, noting

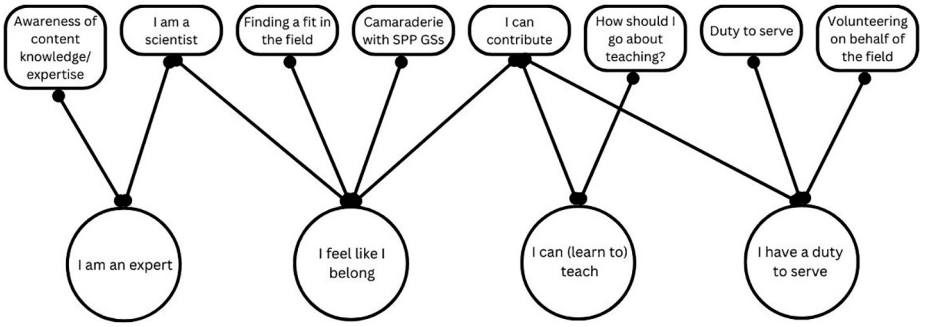

Figure 3.
Themes arising from data analysis

Source: Created by authors

that she was not a "complete expert" (Int.); Zack referred to himself as a "novice expert" (Int.). Regardless of initial discomfort or self-described title, each of these 11 GSs shared that through the SPP, they came to accept the role of "expert," if only a little: "As a graduate student, it can be challenging to recognize yourself as an authority/expert on a topic when you are constantly deepening your understanding of your field. SPP provided an opportunity to recognize some of that expertise" (Tina, Survey).

A second key contribution to GSs recognizing their own expertise came from working with people *outside their field*. Specifically, 14 GSs described that they did not feel like experts *compared with those within their field* but recognized their expertise when compared with the average person (i.e. the TCs). Suzanne articulated, "I don't really feel like an expert in my field. But I feel I definitely have enough experience, and I guess 'expertise', to teach those [in the SPP]. I guess it's all relative in terms of what an expert is" (Int.). Similarly, Daniel commented that his expertise was "not self-evident" before and even early in the SPP. However, the more he worked through the material, the more he realized he knew, which "checked the boxes" for him in terms of being an expert (Refl.End). Furthermore, having faculty and TCs name the GSs as experts allowed them to see themselves in this role (e.g. Penelope, Int.). The ability to locate themselves in terms of expertise among those outside their field allowed GSs to recognize their knowledge and skills, which in turn, helped reinforce their belonging in their field.

Third, naming and treating GSs as experts helped shine a light on what they take for granted in terms of their expertise. Tina commented, "It's funny how those things [content-related ideas] end up becoming so ingrained that you don't really think about knowing them" (Refl.End). For Charlie, the SPP allowed him to "think about how much knowledge I have accrued over the years" (Refl.End). Similarly, when Suzanne looked at her field's NGSS standards, she was excited to feel she could confidently create lessons for each one (Refl. End). This finding demonstrates that the SPP helped strengthen GSs' internal and external recognition as well as their acknowledgment of their content knowledge competence through their teaching "performance."

I feel like I belong

After participating in the SPP, 27 of the 28 GSs made comments consistent with an increased sense of belonging in their field. Their responses fell into three themes. The first is that GSs repeatedly described "finding a fit" within their field. A common statement was that the GSs originally felt they needed to fit the narrow role of researcher or faculty to be a member of their disciplinary community. However, after the SPP, 17 of the 28 GSs shared that they felt they could find work, colleagues and activities within their field that resonated with them and that they did not feel constrained by a "mold":

> Prior to [the SPP], my professional identity revolved around what I call a Hollywood portrayal of a scientist; working in a well-lit lab with a lab coat nearby and a computer spitting out numbers, and also very individual. [The SPP] helped me re-center my own personal values, which are more communal in theme, and apply those back to my professional STEM identity. (Bert, Survey)

Furthermore, GSs considered different ways that they could be useful in their field, and expanded their understanding of what belonging to a field means. Beatrix shared:

> I think one of the biggest impacts [the SPP] has had has been broadening my definition of being an engineer and scientist. . .This class helped me better identify as a professional by. . .showing me that the skills I have that aren't stereotypical STEM skills are still equally as valuable. (Refl. End)

The second theme related to belonging was meeting others like themselves. Twenty-two GSs mentioned finding a supportive group of people in their fellow SPP GSs. For example, Fiona shared that hearing others' similar struggles helped her realize she was not an "impostor" in her field (Refl.End). Robert shared that one reason the SPP impacted him was because he "[. . .]had an opportunity to step outside my lab group, step outside my own department, for the first time, really[. . .] I definitely felt part of [the University] in a way I haven't had before" (Int.). Similarly, Fiona said "getting the chance to discuss teaching and learning with people in other fields" was something that helped reinforce her professional identity (Refl.End).

Finally, four GSs reported that the SPP had reawakened excitement in their field and research. For these GSs, it was the act of teaching/communicating with the TCs that led to this feeling. For example, Quentin said, "I get the most enjoyment from my topics when I get to teach the bigger concepts and see the big light bulbs turn on for students" (Refl.End). In fact, this reawakening of enthusiasm had a particularly strong impact on Willow: "[The SPP][. . .]made me excited again[. . .][I was debating dropping out of grad school for a bit[. . .] so being able to get excited about it again, was really helpful and necessary" (Int.). As can be seen, the SPP helped GSs validate that they were/could be valuable members of their disciplinary community. This finding demonstrates that the SPP helped support GSs feel they belonged to a field that has an important role to play in society as they (re)considered how they might use their expertise meaningfully. Furthermore, the GSs recognized (internal recognition) that they had the competences and abilities (performances) to be a vital part of their STEM community.

I can (learn to) teach

Through the SPP, all 28 participants gained awareness that they can build the necessary skills to be an effective teacher, whether the "teaching" were to take place in a classroom or an industry workroom. Lionel said, "I will be able to use this class when I need to TA future classes and anytime that I need to teach another person some new information" (Refl.End). Furthermore, all participants saw that teaching-related skills were transferable to the workplace and beyond, and not just beneficial to those considering academic careers. For example, John commented that skills learned in the SPP helped him communicate more effectively in his work environment in industry (Int.). GSs noted that the structured opportunities to learn about teaching – the 5E workshop, drafts of their lesson plans with feedback, topics covered in the GCOLL course – built confidence in their teaching ability. Fiona explained "This semester I evolved as a teacher by becoming more confident in my abilities and beginning to see the importance of teaching to my professional identity" (Refl. End).

In addition, 16 participants reported that they are now better able to consider their audience when communicating technical information, an essential aspect of scientific communication. Tina said, "It provided an opportunity to continue to think about how I can tailor my presentations/communication to the appropriate level for my audience" (Survey). Others shared that taking their audience into consideration means they are better able to "pitch" their research to those outside their field (e.g. Caroline, Refl.3) and break down complex topics so as not to confuse people (e.g. Ursula, Int.). Although it was *not* the SPP's intention to develop future instructors, GSs left the SPP with greater confidence that any type of "teaching" in their future would be more effective given what they had learned. This finding demonstrates that the SPP helped strengthen GSs' competence and performance around "teaching" others (in many different ways and contexts) about their STEM field.

I have a duty to serve

Twenty-four of the 28 GSs discussed how possessing rich STEM knowledge means one has a "responsibility," or "obligation" to apply or share this knowledge in service to society. This feeling aligns with professional STEM identity components of knowing one's discipline's role in society and using one's expertise meaningfully. As Hattie pointed out, "academia is a privilege that not everyone has or wants to have" and that "knowledge is power but if only belongs to the scientists and engineers, we continue to create a disparity" (Refl.3). Consequently, GSs asserted that those with graduate degrees need to "find some outlet to use science for the public good" (Bert, Refl.3) because "obtaining disciplinary knowledge and skills [through a graduate degree] imposes a moral responsibility to contribute and improve one's community" (Daniel, Refl.End). Ursula shared that through SPP, she no longer sees herself simply as a GS, but rather as a scientist with a "major role to play" in using her knowledge to benefit society (Refl.End).

Thinking specifically about how they might make an impact, 13 of the GSs spoke about needing to bridge the information gap between scientists and the public. Eleanor explained:

> [I]n every job I have held as a scientist for a public agency, I have observed a huge communication gap between the agency and the public, leading to distrust and other negative consequences[. . .] Because of these experiences, I[. . .]have been feeling the lack of stewardship in the science I was participating in, which led me to explore a different path and return to school. (Refl.3)

To bridge this gap, several GSs noted the need to support K-6 science education and educators (e.g. Suzanne, Int.; Max, Refl.3; Adelaide, Refl.3), whereas others wanted to mentor colleagues embarking on a scientific career (e.g. Ursula, Int.; Ivan, Refl.End). Although at the core of the SPP is GSs supporting TCs (and thus using their expertise meaningfully), we were pleasantly surprised that GSs felt so strongly about their duty to help others using their expertise. This finding demonstrates that the SPP provided GSs with opportunities to ponder their field's role in society and how they might meaningfully use their expertise, as well as the many different ways they might perform their STEM expertise for the greater good.

Discussion

The purpose of this study was to explore how participating in the SPP strengthened GSs' professional identities. The data showed that the SPP did, indeed, support the strengthening of all different components of STEM professional identity. Importantly, the fact that these findings were universal across our participants and did not appear to vary by race/ethnicity, gender, field of study, etc. is encouraging. Here we discuss our results and implications for research and practices.

STEM professional identity consists of being recognized and recognizing oneself as a STEM professional, learning the skills and knowledge of one's field, understanding the role of one's field in society, and considering how to use field-specific expertise in a meaningful way (Carlone and Johnson, 2007; Hazari *et al.*, 2010). Our results show that the SPP supported GSs in strengthening their professional identities in three key ways. First, GSs' feelings of enhanced professional identity came from being seen as an expert, and then *actually being the expert* during interactions with TCs. The SPP gave GSs an authentic practical application for their expertise because the TCs had a genuine need to know the scientific content for their lessons. In other words, instead of simply understanding how to use their disciplinary expertise in the abstract, the SPP allowed GSs to experience this concept firsthand by meeting the TCs' needs. This is valuable practice, as GSs must understand the broader impacts of their field and research and be able to talk about it

(NASEM, 2018; Golde, 2006). The importance of an authentic, practical application of expertise is consistent with studies showing that a socialization aspect, where GSs take on their discipline's knowledge and skills, is important for developing and/or strengthening professional identity (Macbeth *et al.*, 2021; Mantai, 2017; O'Neill *et al.*, 2019; Weidman *et al.*, 2001).

Second, through the SPP, GSs found that they did not have to fit a particular STEM persona, which enhanced their sense of belonging in their field. Gardner (2008) found how not "fitting the mold" of GS demographic stereotypes in STEM can lead to attrition. In the SPP, not only did the GSs interact with a variety of other GSs in terms of gender, race, age, etc. but through conversations and activities together, GSs also saw that there are multiple valid ways to be a STEM professional. Furthermore, sharing their expertise with others rekindled joy about their field. Spaulding and Rockinson-Szapkiw (2012) and McGee (2021) showed that increased motivation and enjoyment of the content supports GS persistence in their degree. Consequently, we believe programs like the SPP, which allow GSs to interact with a variety of people and envision numerous ways to use their expertise, hold promise for helping people remain within their chosen field – an outcome that could disproportionately benefit STEM students from underrepresented populations (Stachl and Baranger, 2020). Interestingly, our data showed a circular relationship between GS professional identity and sharing their expertise in meaningful ways (see Figure 4). GSs found that teaching the TCs and considering other ways to apply their disciplinary expertise resulted in a deeper sense of commitment and belonging to their field and allowed them to consider their field's core values and responsibilities to the public. In turn, GSs saw more ways to integrate with their field via meaningful applications of their expertise and sharing their passion with others.

Finally, even though the SPP was not a training program for teaching, after participating, the GSs found they could teach (or learn to) and communicate scientific

Source: Created by authors

Figure 4.
Relationship between professional identity and sharing expertise meaningfully

information with others in meaningful ways. NASEM (2018) notes that for career readiness and success, STEM graduates need skills, such as effective communication and collaboration, which are found in the act of teaching. It was also important for GSs to see that technical communication (i.e. teaching) is a critical scientific skill. Previous studies report students feeling conflicted between research and teaching, even questioning their abilities or fit as a scientist because they enjoy teaching (Brownell and Tanner, 2012; Love Stowell *et al.*, 2015). Through the SPP, GSs learned that research and teaching are not mutually exclusive. On the contrary, one must be a good teacher/communicator to be a valuable member of their STEM discipline.

These results lead us to consider implications for practice and research alike. In terms of practice, the literature on (STEM) graduate school indicates that GSs often feel isolated or that they lack a strong sense of community (Jensen and Jetten, 2015; Mantai, 2017; Noonan, 2015). In the SPP, GSs were able to interact with people outside (and inside) their field over a prolonged period – an unusual opportunity during graduate school. Throughout the semester, communities of practice (Lave and Wenger, 1991) both between the GSs, as well as between TCs and GSs, gave GSs time to increase socialization in their programs and fields (O'Meara, 2008; Weidman, 2001; Mantai, 2017) and supported them in learning more about the values and goals of their STEM disciplines (Tomlinson and Jackson, 2021). We might recommend other graduate programs or institutions consider ways in which they could be intentional in creating interdisciplinary as well as disciplinary communities of practice.

In addition, we hypothesize that the SPP helped GSs build their confidence precisely *because* teaching was so outside their comfort zone. Achieving difficult tasks is a wonderful reminder of our own capabilities. But perhaps more importantly, having everyone in the cohort working outside their comfort zones leveled the playing field and may have allowed the GSs to be more open to learning, reflecting and working with others. We would encourage graduate programs and institutions to consider ways in which they create safe environments and opportunities within which GSs can operate outside their comfort zones and perhaps even their discipline. Not only could these types of activities be a fun way to build community, but might also allow those who typically experience impostorism in their field to shine at a new task.

We recognize that not all disciplines, graduate programs and/or departments see the value in GSs taking the time to engage in activities that are outside the "typical" course of study. Some STEM advisors may not want their GSs to take time away from their research or they may not see the relevance of these activities (Denecke *et al.*, 2017; Matthews *et al.*, 2022; Porter and Phelps, 2014). However, research demonstrates that out-of-class experiences can be quite impactful to GSs in terms of building a professional network and truly understanding a field, its norms and its expectations (Liddell *et al.*, 2014). Furthermore, activities that are often characterized as "outreach" or "educational outreach" performed by STEM GSs have been shown to increase program retention, persistence to degree and self-efficacy, in addition to a strong professional STEM identity (Matthews *et al.*, 2022; Rethman *et al.*, 2021). Feldon *et al.* (2011) even found that when STEM GSs engaged other students through inquiry-based teaching, the GSs' research abilities improved significantly. Given the abundance of empirical research demonstrating the benefits of GSs' "branching out" beyond their course of study, we would urge graduate programs and departments to share this research with their faculty and craft opportunities that provide interdisciplinary partnerships, extended communities of practice and pushing GSs to try something new while balancing the necessary workload of the course of study. As a model of one type of such opportunity, it should be noted that the SPP's outcomes were consistent across STEM disciplines, did not require GSs to take on large amounts of coursework, nor did it cost much

beyond "grocery store science" materials for the various lessons. This makes the SPP (and/or its key components) sustainable to implement and adaptable to different institutional contexts.

This study also holds implications for research. Most importantly, it is vital we continue exploring ways to attract, support and retain GSs from populations typically marginalized in STEM. As previously discussed, some strides have been made related to women in STEM, but there are still unacceptable gaps in terms of advanced degree attainment for many populations. Although the SPP did not specifically target GSs from these populations, we did recruit a significant proportion of our participants from these populations. However, these GSs *did* self-select into the program, which leads us to wonder why they did, whereas others from these populations did not. We see fruitful avenues of research in terms of speaking with STEM GSs from populations typically marginalized in STEM and listening to *what they want to do* with their advanced STEM degree. McGee (2021) has argued that programs and careers that embed an equity ethic – that is, a set of values that is concerned with (racial) justice and helping those living with the outcomes of inequities – can attract and retain students of color in STEM programs. By learning more from GSs about what they *need* from their graduate programs, we can better design courses and opportunities to meet those needs.

The results of this study also lead us to reemphasize the importance of attending to the cultivation and development of professional identity in (STEM) graduate education research and connecting this research to the appropriate stakeholders. As Hoffman-Longtin *et al.* (2021) note, "Although the graduate student socialization and identification process has been discussed for more than 30 years, little has changed in practice" (p. 120). Certainly, there has been a steady stream of research on the topic during the past three decades, yet this statement leads us to believe that this research has not found purchase in graduate programs. Consequently, we urge researchers to take up this theoretical framework when designing graduate-level interventions – particularly if they are discipline-specific, as we find faculty most open to "close translations" of interventions (i.e. translating an intervention in a chemistry course to another chemistry course). Indeed, we urge these researchers to go one step further and share their results surrounding the benefits of supporting the development of a professional identity in GSs with their peers. Sturtevant and Wheeler (2019) comment that faculty will often not change their (pedagogical, advisory, mentoring, etc.) practices until they have a personal experience that pushes them to try something different – researchers with empirical data have the ability to be incredibly persuasive in these instances.

Limitations

Although the findings are encouraging, this study is not without limitations. Our sample size was relatively small, data were solely self-reported and much of the study occurred during the COVID-19 pandemic. However, we collected a variety of data types over five different semesters, from students with different demographic characteristics, studying in a variety of programs. These triangulation efforts along with a disciplined analysis process give us confidence in the themes observed. And although we cannot know the full impacts of the COVID-19 pandemic and the complexities involved in that period of time on the SPP, we are heartened to know that even GSs who participated in the SPP from March 2020 onward, still reported benefits from their participation.

Conclusion

Given the need to better help STEM GSs obtain an education that will serve them in a variety of careers, as well as to support them in feeling that they belong and can persist in their field, graduate education programs would be wise to increase focus on the cultivation

and development of GSs' professional identity. In line with Boyer's (1990) call to produce a "new generation of scholars" who are "intellectually vibrant and more responsive to society's shifting needs" (Boyer, 1990, pp. 73–74), this study suggests the benefits of creating "new generation" of unique programming for GSs that strengthens their professional identities through authentic, interdisciplinary partnerships.

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Supplementary material

The supplementary material for this article can be found online.

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