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RESEARCH ARTICLE

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Impacting elementary STEM teacher leadership identities

Kelsey Quaisley[1] | **Rachel Funk**[2] | **Leilani Pai**[3] | **Sally Ahrens**[2] | **Wendy M. Smith**[4] | **Amanda Thomas**[5]

[1]Department of Mathematics, Oregon State University, Corvallis, Oregon, USA

[2]Center for Science, Mathematics, and Computer Education, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[3]Department of Mathematics, Denison University, Granville, Ohio, USA

[4]Center for Science, Mathematics, and Computer Education & Department of Mathematics, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[5]Department of Teaching, Learning, & Teacher Education, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

Correspondence

Kelsey Quaisley, Kidder Hall 368, 2000 SW Campus Way, Oregon State University, Corvallis, OR 97331-4605, USA.

Email: quaislek@oregonstate.edu

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Abstract

Learning science, technology, engineering, and mathematics (STEM) subjects starting at a young age helps prepare students for a variety of careers both inside and outside of the sciences. Yet, addressing integrated STEM in an elementary school setting can be challenging. Teacher leadership is one way to address this challenge. The purpose of this qualitative, descriptive case study is to understand how participation in the NebraskaSTEM Noyce Master Teaching Fellowship project impacted elementary STEM teacher leadership identities. Our findings suggest participation in the project contributed to different layers of teacher leadership identity (as a STEM learner, as a STEM teacher, and as a STEM teacher leader). These findings suggest professional development should be tailored to address empowering specific layers of STEM teacher leaders' professional identity. Other teacher leadership development projects may want to consider how to structure their projects to empower teachers based on the identities and experiences of those teachers.

KEYWORDS

elementary education, professional identities, STEM, teacher leadership

1 | IMPACTING ELEMENTARY STEM TEACHER LEADERSHIP IDENTITIES

Increasingly, preparing students for future careers requires significant attention to STEM learning. Analysis of a broad range of careers indicates the number of careers requiring some STEM knowledge outpaces the number of students with adequate STEM knowledge, resulting in an "accelerating" shortage of talented STEM workers in the United States (US; National Science Board, 2024, p. 2). This concern is compounded when considering issues of inclusion and equity. Although the majority of US college students are women or members of racially minoritized groups, they are underrepresented in undergraduate STEM programs, accounting for far less than half of undergraduate STEM degree recipients (Pew Research Center, 2021). These statistics point to a need to better support students in learning STEM subjects throughout their schooling. Children develop interest in STEM during elementary school (Dabney et al., 2013), so providing high-quality opportunities for elementary students to engage in STEM learning, especially in high-need schools, is vital to supporting their future involvement in STEM. We define high-need schools as having a high percentage of students in poverty, a high percentage of teachers teaching outside their area of certification, and/or a high teacher turnover rate.

Precisely how to approach elementary STEM teaching remains unclear (El Nagdi et al., 2018), but integrated approaches to teaching and learning STEM have gained popularity for their potential to increase student interest and achievement (National Research Council [NRC], 2014). Integrated STEM teaching combines multiple STEM topics in a single lesson or unit (Moore et al., 2014) and often emphasizes problem-based approaches to learning (NRC, 2014). It is particularly well-suited to generating student interest and understanding that spans disciplines but presents unique challenges in the classroom. Integrated STEM has not been emphasized in the United States until relatively recently, so teachers, particularly elementary teachers without specific STEM pedagogy training, may be unfamiliar with it or feel unprepared to teach integrated STEM lessons (El Nagdi et al., 2018; Holincheck & Galanti, 2023).

Schools are complex systems, and teacher leadership is one way to systemically address complex issues around improving STEM teaching and learning. Wenner and Campbell (2017) define teacher leaders as "*teachers who maintain K-12 classroom-based teaching responsibilities, while also taking on leadership responsibilities outside of the classroom*" (p. 140, emphasis in original) in order to distinguish teacher leaders from other kinds of educational leaders (often in administrative roles). Teacher leaders have the potential to maximize impact because they can, for example, not only use effective STEM teaching practices in their own classrooms, but also disseminate ideas to others within their professional networks and empower and support teachers in teaching STEM at their schools.

Becoming a teacher leader involves, among other things, developing a strong professional identity within communities of practice (Barth et al., 2024; Wenner & Campbell, 2018); communities of practice involve people coming together to address a particular issue in collaboration with each other (Wenner & Campbell, 2018). Exactly how teachers transition to teacher leaders is not well understood; professional identities are complex, socially constructed, context-dependent, dynamic, and intertwined with myriad professional and personal characteristics (Quaisley et al., 2023). Nonetheless, some research suggests engaging in new experiences, reflecting on those experiences, and incorporating external feedback are beneficial to developing a teacher leadership identity (Sinha & Hanuscin, 2017). Teachers often feel they lack the STEM content knowledge required to be a STEM teacher leader (e.g., Corp et al., 2020), so developing expertise in STEM may be particularly important to developing a STEM teacher leadership identity. A professional project that provides teachers with opportunities to enhance their knowledge of STEM content and pedagogy through new experiences, as well as provides peers with whom they can reflect and receive feedback, has the potential to positively impact teachers' sense of belonging, empowerment, and leadership identities. In this study, we examine one project, NebraskaSTEM, and its impacts on the leadership identities of elementary STEM teacher leaders.

2 | PURPOSE AND RESEARCH QUESTIONS

The purpose of this study is to investigate how participation in the NebraskaSTEM Noyce Master Teaching Fellowship project impacted elementary STEM teacher leadership identities. In this qualitative, descriptive case study we seek to address: *How did the project impact the STEM teacher leadership identity development of elementary STEM teacher leaders?*

3 | LITERATURE REVIEW

Although math and science are regular parts of the elementary curriculum, recent years have seen a push to add computer science and engineering for young students, along with more integrated STEM teaching and learning (El Nagdi et al., 2018; Maiorca & Mohr-Schroeder, 2020). Relatively little research has been done to identify effective models of STEM education in elementary schools (Chiu et al., 2015); however, STEM-specific professional development is important for elementary teachers to learn about the content and pedagogy associated with teaching and learning integrated STEM (El Nagdi et al., 2018). Relatedly, it is important for elementary teachers to identify with integrated STEM as learners, teachers, and leaders in order to support integrated STEM enactment. Widespread integrated STEM enactment can be supported by professional networks and teachers with strong integrated STEM identities who take on leadership roles. Accordingly, we present relevant literature in three categories: elementary STEM, teacher leadership, and professional development.

3.1 | Elementary STEM

Effective teaching of STEM content across elementary and secondary education is vital for preparing students for STEM careers (NRC, 2014). Authentic learning experiences grounded in real-life contexts provide opportunities to develop students' STEM knowledge and foster their innovation and creativity. Moreover, research suggests long-term learning depends on connected learning experiences (Bransford et al., 2000), such as those offered by integrating STEM content. Because US elementary teachers are already expected to teach multiple content areas throughout the day, often around an overarching theme, elementary classrooms are ripe with potential for integrated STEM learning experiences (NRC, 2014).

Another reason to focus on STEM at the elementary level is students can begin to develop perceptions of and interest in STEM during and even prior to the elementary grades (NRC, 2014). Dabney et al. (2013) reported 41% of study participants became interested in STEM during elementary school. Many elementary students have already begun to develop conceptions of STEM professionals and beliefs about who can participate in STEM (Luo & So, 2023). Hence, the elementary grades are a meaningful time to develop students' conceptions of and interest in STEM.

However, preparing and supporting elementary teachers to teach STEM content is challenging. Many elementary teachers experience anxiety and low self-efficacy in teaching mathematics and science content, which can negatively impact students' learning and achievement (Schaeffer et al., 2020). Additionally, some elementary teachers believe students should be taught mathematics as the teachers themselves were taught (Harbin & Newton, 2013), using rote memorization and drill procedures. Since elementary teachers' mathematics beliefs are strong predictors of instructional practices (Hughes et al., 2019), some elementary teachers may experience difficulties developing STEM learning environments that center on student innovation and creativity for solving open-ended problems.

Indeed, research suggests integrating multiple STEM disciplines and providing authentic STEM learning experiences in the elementary classroom is challenging (Guzey et al., 2016; Maiorca & Mohr-Schroeder, 2020). Considering the specific challenges that teachers in Nebraska encounter in teaching STEM, Sutton et al. (2015) found elementary science teachers' lowest self-ratings were in areas of preparedness to *facilitate project-based learning experiences in science* and *understand and integrate multiple disciplines into the instructional design* (Sutton et al., 2015). In addition to teachers' anxiety, self-efficacy, and beliefs about teaching STEM content, struggles to effectively integrate STEM may also be due to content and pedagogical knowledge gaps (Guzey et al., 2016). Taken together, these findings point toward a need to support elementary teachers' integrated STEM teacher identities.

3.2 | Teacher leadership and identity

Teacher leadership offers a promising approach to supporting elementary teachers to develop stronger integrated STEM teacher identities and effectively integrate STEM in their classrooms. In the decentralized US education system, elementary teachers are largely prepared as "generalists" without particular specialization in integrated STEM or other content areas. Developing teacher leaders is an effective way to utilize a distributed leadership framework (in which teachers collectively share responsibility and authority for leadership activities; Hopkins et al., 2013) and thus better support more teachers in integrating STEM at the elementary level. We draw on Wenner and Campbell's (2017) definition of teacher leaders as those who take on leadership responsibilities while also serving as classroom teachers. Within the STEM teacher leadership context, we conceive of leadership responsibilities as those that include, but are not necessarily limited to, taking active roles in supporting professional learning in their schools, such as leading STEM-focused professional development workshops or assisting other teachers in integrating STEM; being involved in policy and decision-making around issues in STEM teaching and learning; and generally working toward improving students' learning and success in STEM disciplines.

Teacher leadership has numerous potential benefits. Wenner and Campbell (2017) summarized the mixed effects of teacher leadership in the literature. In general, teacher leaders reported increased job satisfaction, confidence, and empowerment; increased professional growth and leadership capacity; and positive recognition from administrators. Yet, teacher leaders also reported increased stress or difficulties associated with increased responsibilities, as well as negative changes in relationships with peers. For example, "it disrupted the egalitarian norms typically seen in schools" (p. 151). Overall, however, Wenner and Campbell point to positive outcomes for teacher leaders and their colleagues, provided good work relations exist among teacher leaders and colleagues. Pineda-Báez et al. (2020) highlight the importance of these relationships in various contexts. Exemplar cases of teacher leaders in Australia, Canada, and Columbia underscore the significant role of principals in fostering a distributed leadership model.

Teacher leadership depends on socio-cultural and institutional contexts; understanding teacher leadership identities involves examining not only personal and professional characteristics but also the complex systems in which teachers are embedded (Sinha & Hanuscin, 2017). In their study of the development of teacher leadership identity, Wenner and Campbell (2018) describe the importance of communities of practice for developing professional identities. Furthermore, they adopt a model of professional identity from Carlone and Johnson (2007) that emphasizes three components: competence as knowledge and understanding of content, performance of practices, and recognition by oneself and others as embodying a professional identity. Galanti and Holincheck (2022) build on Carlone and Johnson's and Hanna et al.'s (2020) models of professional identity, arguing successful STEM integration requires elementary teachers to develop stronger integrated STEM teacher identities. Fortunately, research suggests teacher leaders can positively influence teachers' professional identities (e.g., Hopkins et al., 2013; Quaisley et al., 2023).

Research also suggests engaging in new experiences, reflecting on those experiences, and incorporating external feedback are beneficial to developing a teacher leadership identity (Sinha & Hanuscin, 2017). Further research is needed, however, to understand what kinds of experiences and opportunities support teacher leadership identity development in the integrated STEM context because STEM teachers tend to equate their content expertise with their professional identities (El Nagdi et al., 2018). Note these phenomena do not necessarily exist in other content areas. For example, a reading coach may be more knowledgeable in how to teach students to read, but they would not necessarily be considered to be better reader than their colleagues. Yet, a STEM coach would likely be expected to have more STEM content knowledge than their colleagues. Hence, developing a STEM teacher leadership identity might include requisite expertise that is not necessarily characteristic of teacher leadership identities more generally. As a result, the field needs to grow in specifically understanding how STEM teacher leadership identity is cultivated. Such research needs to build on the field's understanding of STEM teacher identity development (El Nagdi et al., 2018) and how STEM teacher leaders can positively influence their colleagues' professional identities and strengthen their own (Quaisley et al., 2023).

3.3 | Professional development

Existing professional development projects that emphasize project-based learning and STEM integration have reported success in enhancing teachers' understanding of STEM and bolstering their self-efficacy for teaching it. Barrett et al. (2015) provided evidence that teacher professional development has a positive impact on students' performance. However, teachers may require more support to effectively plan integrated STEM lessons. Following a professional development project, Guzey et al. (2016) found teachers successfully developed integrated STEM lessons, but the extent of science and mathematics integration in the lessons varied. Although there are many research studies about the impact of teacher professional development (e.g., Zhou et al., 2023), integrated STEM is a recent enough phenomenon (since 2010) that fewer studies exist regarding features of effective professional development for elementary teacher leaders to promote integrated STEM.

Many publications related to the impacts of professional development come from largely quantitative evaluations and often draw on multiple-choice self-report survey data (Zhou et al., 2023). Those publishing about the impacts of professional development are typically observers (either external or internal) of the projects and rarely center participants' voices. There is a real need to understand teachers' experiences in professional development through teachers' perspectives, particularly to tease out differential impacts of various professional development experiences on unique individuals.

4 | CONCEPTUAL FRAMEWORK

Our conceptual framework builds on Galanti and Holincheck's (2022) model of integrated STEM teacher identity, which itself builds on Hanna et al.'s (2010) framing of teacher identity and Carlone and Johnson's (2007) framing of science identity. Galanti and Holincheck describe STEM teacher identity as an intersection between STEM learner identity and teacher identity. STEM learner identity is a constellation of one's desire to learn STEM content, recognition of self as a STEM person (via themselves or others), and belief in their capabilities to understand STEM content and perform STEM tasks. STEM teacher identity is a constellation of a STEM teacher's motivations and interest in teaching integrated STEM, belief in their capabilities to teach integrated STEM (self-efficacy), and perceptions of themself (self-image) and their tasks (task perception) as an integrated STEM teacher.

Because we are interested in STEM teacher *leadership* identity development, we intersect a third layer, teacher leadership identity, amidst STEM learner identity and teacher identity. We describe STEM teacher leadership identity in a similar fashion: a constellation of a STEM teacher leader's motivations and interest for influencing the adoption of integrated STEM into the school system, belief in their capabilities to influence others to integrate STEM within their school system (self-efficacy), and perception of themself (self-image) and their tasks (task perception) as an integrated STEM teacher leader. We additionally acknowledge the importance of recognition

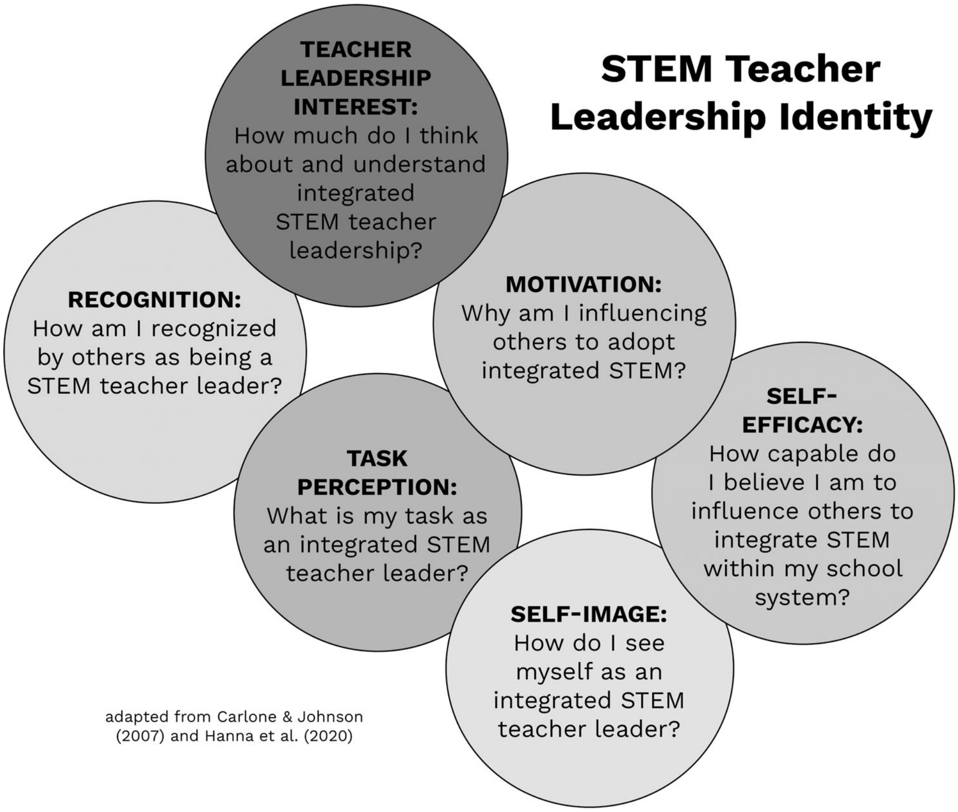

FIGURE 1 Components of STEM teacher leadership identity.

from others in identity development (Carlone & Johnson, 2007). Settings, specifically the communities of practice in which teachers work, are critical to developing teacher leadership identity (Campbell et al., 2022). Thus, our conception of STEM teacher leadership identity encompasses self-image and recognition of self as a STEM teacher leader via others. Note that for teacher leaders, influencing others is not limited to other teachers but may include administrators. We expand on this third layer in Figure 1.

5 | METHODS

This research project is part of a larger set of nine comparative cases of Noyce projects (Barth et al., 2024; Yin, 2009; Yow et al., 2021) developed as part of a collaborative Noyce research grant focused on investigating the persistence and professional trajectories of Master Teaching Fellows (MTFs). We focus here on a single case of one STEM teacher leadership professional development project and how it was structured to improve integrated STEM teaching and positively impact participants' identities as teacher leaders. This case is bounded by time (2018–2020), geography (one leadership project in a single US state), and scope (teacher leadership related to elementary integrated STEM in a single professional development project). Because leadership development projects are necessarily specific to local contexts, people, and needs, examining one such project as a case is an effective way to understand key components and decisions and allows others to adapt these components to their own local contexts.

5.1 | Context of the study

NebraskaSTEM is a Noyce MTF five-year project (#1758496) funded by the US National Science Foundation's Robert Noyce Teacher Scholarship Program (Noyce). Noyce programs partner with and focus on high-need schools. NebraskaSTEM was designed to enhance STEM instruction in rural, high-need elementary schools across Nebraska. Key project components include graduate courses, a community of peers, and leadership activities.

During the first 2 years of the project, the majority of MTFs completed a 14-month Master of Arts degree program in elementary education with specialization in STEM education and participated in professional development about teacher leadership. STEM-specific professional development was planned for the 2020–21 school year but was postponed due to COVID-19. In subsequent years, MTFs are focused on developing and implementing their own leadership initiatives with support from the NebraskaSTEM community. The master's program included content courses in each STEM discipline[1]; pedagogy courses that focused on effective teaching practices, integrating STEM disciplines, and rural education contexts; education research courses that culminated in a master's thesis; and courses specific to teacher leadership.

One of the goals of the NebraskaSTEM project was to create and sustain a community of peers with whom MTFs can identify, collaborate, and share ideas and resources. MTFs completed coursework as a cohort. In the first summer of the project, NebraskaSTEM intended to foster a community among this cohort by encouraging MTFs to stay in the same residence hall as they completed courses on campus, which many MTFs did. This helped MTFs build a community that they have continued to use for support in teaching integrated STEM and to share ideas about improving instruction in MTFs' classrooms.

To develop MTFs' leadership roles locally, NebraskaSTEM supported MTFs' planning and implementation of local STEM innovation initiatives. The project gave MTFs a time and venue to plan their initial STEM initiatives by incorporating planning time with a group of peers into the rural education course. To develop MTFs' leadership roles beyond their local contexts, expand their professional networks, and increase their understanding of educational systems, NebraskaSTEM encouraged MTFs to share their knowledge and expertise through larger-scale opportunities such as professional conferences.

5.2 | Participants

In Spring 2018, 14 highly qualified elementary grade teachers were selected to become MTFs in the project and learn how to effectively enact integrated STEM both in their classrooms and in their leadership activities. They were chosen via a competitive process that required applicants to submit letters of recommendation; essays about their goals for participating in NebraskaSTEM; evidence of good teaching (via a recording of a lesson); standardized test scores (PRAXIS or GRE); college transcripts; and a resume. The MTFs were chosen to be geographically diverse, coming from different rural schools across the state. All were current classroom teachers for one or more elementary grade levels. Closely aligned with the state elementary teacher demographics (95% white), this cohort includes 3 men and 11 women; one Hispanic and 13 white teachers. To protect the identities of our participants, we chose pseudonyms for each MTF and used gender-neutral pronouns (they/them).

5.3 | Data collection

This study draws from formal interviews with NebraskaSTEM MTFs in Fall 2018 and Summer 2020 as well as annual documents about NebraskaSTEM (e.g., the original proposal to NSF, annual reports to NSF, notes from informal interviews with project personnel, and evaluation reports). Each of the 14 MTFs was individually interviewed in Fall of 2018 about their teaching and leadership experiences and their teacher leadership identities using a common protocol designed by T-Lead. Follow-up interviews were conducted with MTFs in Summer 2020 using a similar protocol. Additionally, as part of the larger research project, one peer and one administrator for four MTFs were interviewed. All interviews were conducted via Zoom, and the audio files were transcribed using Temi and cleaned by the research team.

5.4 | Data analysis

Two to three members of the research team independently coded each interview transcript using a codebook developed by the larger Noyce research project (Criswell et al., 2022). The codebook was based on teacher leadership development literature (e.g., Huggins et al., 2017; Sinha & Hanuscin, 2017; Wenner & Campbell, 2018), with codes clustered into major categories: professional identity, professional trajectory, Noyce program features, school system features, and teacher leadership. The researchers averaged approximately 90% agreement across all Fall 2018 transcripts and subsequently met to reconcile their codes, having discussions that resulted in some researchers adjusting their codes to reach 100% consensus (Saldaña, 2016). The Summer 2020 transcripts were coded similarly, with groups of two to three researchers coding individually and then meeting to reach 100% consensus. Each coded transcript was then summarized along the major code categories using an Excel spreadsheet. For this qualitative, descriptive case of the NebraskaSTEM Noyce project, we examined summaries under the *Noyce program features* category for evidence of the direct impacts of NebraskaSTEM as described by participants, and *teacher leadership* and *professional identity* categories to better understand the effect of stated impacts on teacher leadership identity.

[1]These disciplines include STEMs. NebraskaSTEM personnel specifically selected physics within the science domain and computer science within the technology domain based on a Nebraska Needs Assessment (Sutton et al., 2015).

Statements that were coded within the *professional identity* category included the main subcode *Becoming/Being* to capture data indicating how the characteristics of the MTF or the nature of their interactions with colleagues or administrators helped them develop or exhibit an identity as a teacher leader. This included statements indicating the MTFs' belief in and perceptions of themselves as teacher leaders (i.e., their self-efficacy and self-image). We included another subcode, *Balancing*, to further capture data in which the MTFs talked about balancing multiple identities, how these identities interacted or related, and how or when they might have assumed different identities. As an example, the increased validation an MTF receives for teacher leadership work (i.e., recognition) could strengthen their STEM teacher identity (e.g., when practices the MTF believed in now became more accepted by colleagues). In this way, we aimed to capture interactions between different layers of our conceptual framework: STEM learner identity, STEM teacher identity, and STEM teacher leadership identity.

From the summaries of each interview transcript, we created an initial set of assertions, grouped by themes, related to Noyce project impacts on STEM teacher leadership identity, and created documents with supporting evidence for those assertions and themes. We then reread transcripts, focusing on the excerpts coded as Noyce program features, teacher leadership, and professional identity, to look for any additional evidence of the project's impact on participants that confirmed or disconfirmed our assertions. We also provided project personnel the opportunity to review our case synthesis as a form of member-checking and to request revisions or affirm our analysis as reflective of their experiences with the MTF project.

To enhance description of the project and MTF activities, the research team analyzed the funding proposal, evaluation reports, and annual reports. Our document analysis focused on opportunities for leadership and professional development activities, as well as project personnel's goals for the project and rationale for project activities. The synthesized project description underwent peer review by members of the research team to ensure validity (Creswell & Poth, 2018). Analysis of these data provided context for the various impacts of the project that MTFs identified in interviews. We used administrator and peer interviews from four MTFs as a qualitative trustworthiness lens to triangulate those MTFs' self-perceptions.

6 | RESULTS

We address the research question: *How did the project impact the STEM teacher leadership identity development of elementary STEM teacher leaders*? in three sections. The first section focuses on how the project impacted MTFs as STEM learners and teachers, which we presented in our conceptual framework as the first two layers of STEM teacher leadership identity. The second section focuses on how the project impacted MTFs as STEM teacher leaders—the third layer of identity. Finally, the third section emphasizes how settings, particularly the communities in which MTFs were embedded, impacted MTFs.

6.1 | Building the first two layers of identity: STEM learner and teacher identity

All 14 MTFs attributed increased STEM knowledge or impacts on their personal instruction of STEM content to the NebraskaSTEM project during the first- or second-year interviews. For example, Mx. Anderson reported the project helped them learn about the bigger picture in STEM and make connections among STEM topics whereas Mx. Martin described how the project made them more inquisitive and confident in their abilities to find answers rather than searching the internet for answers. On learning more about STEM in the project, Mx. Miller said, "Personally, I believe educators have to keep continuing their own education to be the best, and I felt like this has helped me out a lot in those areas that I felt like I was a weaker teacher." Like Mx. Miller, for the majority of MTFs, the gains in STEM knowledge (or competence as STEM learners) intertwined with increases in self-efficacy for integrated STEM instruction. Multiple MTFs explained how the project influenced their lesson planning and curriculum, for instance, by encouraging them to attend to science standards while planning, incorporate more integrated STEM activities into their lessons, or find creative ways to promote STEM careers such as bringing in community members or hosting STEM nights.

Relatedly, many MTFs described the project's impact on their perception of what STEM activities and learning should look like (task perception as STEM teachers). MTFs mainly described shifting their instruction to emphasize collaboration and group work—something Mx. Brown had never done before the project—while reducing micromanaging or giving students the correct answer. Mx. Cox mentioned they used to think teaching math and science was just a matter of going through the workbooks, but as a result of the project, want to push students to dig deeper in STEM content. Mx. Lee described how their beliefs about STEM learning changed as a result of the Noyce project, stating learning is not "isolated," and STEM should be integrated to make it more engaging. For Mx. Ross, the project helped transform their teaching from being more lecture-oriented to student-centered:

> I was a little bit, I don't know if old school's the right word. I would stand up in front and try to help them figure it out, and I think one of the things that I've learned from this is that they actually know how to do it on their own. I just have to be there to support them and facilitate for them and give them supplies and sort of let them figure it out.

The project similarly gave Mx. Long the self-efficacy to teach STEM more ambitiously, enact new STEM activities, and trust that students can figure things out faster than the MTF would have on their own. Thus, Mx. Long and Mx. Ross seemed to shift their STEM teacher self-images toward those of facilitators.

Primary project features that MTFs credited with impacting their STEM knowledge and instruction included the coursework and its emphasis on collaboration. Mx. Brown described how one of their content courses was "very scary and intimidating" and how, at the time, they and the rest of their cohort were unsure of how it would apply to their own teaching. Then they explained that this content knowledge did support their teaching: "when it came time for me to teach it to a third grader, I felt like I knew that knowledge so well that I could easily apply it to them." Mx. Brown also used their own experiences learning in a collaborative classroom to develop collaborative tasks for their students:

> I just love the collaboration that we did [in NebraskaSTEM]... I was always scared to have my students do group work because it would get chaotic and then you lose the classroom management piece of it. And now I feel like I do so much group work with my students because they worked so much better... they really do a great job feeding off of each other, giving each other feedback, collaborating with one another... I felt like if I were to do half of those things in the NebraskaSTEM program on my own, I would probably have had a panic attack. But knowing that I had someone else to rely on, I just, you know you feel a little bit more at ease, and I feel like that's the same way with my students.

Thus, Mx. Brown's experience shows how engaging in collaborative STEM activities provides an opportunity to harmoniously increase competence as a STEM learner, motivation for integrated STEM teaching, and self-efficacy as a STEM teacher. In addition, MTFs' interest in integrated STEM teaching was influenced by the interactive activities in their coursework. Mx. Miller described how they designed science labs for every single lesson they learned in the project or found online, and Mx. Morris incorporated activities they experienced in the engineering course into their own classroom and family fun nights.

6.2 | Building the third layer of identity: STEM teacher leader identity

6.2.1 | Recognition by others

Many MTFs reported that participating in NebraskaSTEM led to increased recognition from peers and administrators of their STEM education knowledge and expertise, which in turn led to them being positioned as leaders by others. As a peer of Mx. Brown described, Mx. Brown morphed from "somebody who wasn't super confident in science" to a STEM content expert and enthusiastic leader in STEM education. A school administrator also commented on how the project increased Mx. Brown's content knowledge and consequently their ability to teach STEM. In their second interview, Mx. Brown described how others view them as a STEM teacher leader: "those primary grade levels—they kind of look to me as far as, 'Okay, should I be doing this? Is this correct, or is this following the standards correctly?'" Furthermore, Mx. Brown shared how the project influenced their self-image as a STEM teacher from a "sage on the stage" to having "students explore on their own and make their own reasonings for what's happening."

Other impacts of the project were less explicit. For example, Mx. Long stated their colleagues and administrators have become more supportive of STEM after seeing how students respond to activities the MTF implemented. While Mx. Long did not directly attribute this change in their colleagues' and administrators' attitudes to the project, they stated their involvement in the project is what prompted their increased interest in teaching STEM. However, some of the activities they incorporated, such as a STEM night, were directly inspired by the project. Thus, an increased interest in (and subsequent enactment of) teaching integrated STEM due to their engagement in various integrated STEM-oriented project activities may have contributed toward some MTFs perceiving others as recognizing them as STEM teacher leaders.

Notably, increased recognition or awareness of MTFs' involvement in NebraskaSTEM often led to new leadership opportunities for fellows within their communities as described by MTFs. District and school leaders offered opportunities to MTFs (e.g., writing curriculum, mentoring new teachers); MTFs also taught coding classes at the local library and presented to pre-service preschool and kindergarten teachers about integrated STEM at their local community college. These activities helped MTFs increase their leadership efficacy. MTFs also positioned themselves for leadership roles by seeking out opportunities to get involved and become advocates for STEM education, as described in the next section.

6.2.2 | Advocating for STEM education

Several MTFs described how participating in the project helped them become advocates for STEM education in their schools, both within and outside of their classrooms. At the classroom level, some MTFs described how the project expanded their thinking in terms of STEM and its impact on possible career pathways for students. For example, Mx. Anderson researched how and when students decide to go into STEM fields for their master's thesis and used this research to inform their own teaching. They found that many students make the decision to go into STEM in elementary school, and exposure to the variety of STEM careers is critical to this decision, especially in small communities where students have less exposure to multiple career paths. Similarly, Mx. Brown stated the project influenced them to "reflect as an educator on 'how am I going to be impacting the students to… go into some type of STEM field?'" especially within the context of their highly diverse school. They further explained they want to show their students that going into STEM is "very doable."

Some MTFs described becoming better advocates for STEM at the school or district level as a result of their participation in NebraskaSTEM. Mx. Ross said because of the project "I have a much greater amount of confidence when approaching my administration about ideas and the idea that I think that science curriculum is important, and I don't have a problem going to battle for that." This effect on Mx. Ross's self-efficacy as a STEM teacher leader may be in part due to increased knowledge of current research on STEM teaching practices. For example, Mx. Sanders described how the influence of their graduate classes and a regional mathematics conference prompted them to advocate for curriculum changes in their school to better reflect current recommended teaching practices. They said NebraskaSTEM has "given me a voice in science, and math, and problem-solving, and engineering. Whereas, I had a voice, but I guess not as strong [as before the project]." Mx. Hall had a similar experience, stating, "the program has given me legs to stand on," and Mx. Mitchell explained that within their school district, STEM had not been a focus, but they were able to share what they learned through NebraskaSTEM with their school to support STEM:

> We've never had a strong background in STEM in our district. It's always been more like the reading and the language arts. And going through this, now it's really given me an open mind…and to actually know what we're pushing forward to the future, and actually get to put some of the input that I learned going through this program to my other colleagues—into my administrators and curriculum directors.

MTFs felt their participation in NebraskaSTEM added credence to their suggestions for curriculum; thus, they felt more confident in sharing their opinions on curriculum. Furthermore, some participants described advocating for STEM education by offering new professional development opportunities for other teachers. As Mx. Roberts explained:

> I feel like I put myself out there to lead professional development more often. So I've really gone to my principal and said, "hey, I want to get more coding in the following ways in these classrooms, could someone cover my room while I go help this teacher?" Or like when we have our PLC time, "can I present on whatever the topic is that I want to just put out there?" And I guess it's helped me to be a better facilitator for my peers.

Hence, the NebraskaSTEM project influenced MTFs' self-efficacy and interest as STEM teacher leaders to advocate for integrated STEM at multiple levels in their school systems.

6.3 | Access to communities of practice and decreased feelings of isolation

A primary impact of the NebraskaSTEM project was increasing MTFs' access to communities of colleagues and scholars with whom they could share ideas, collaborate, and for some MTFs, develop deep bonds and decrease feelings of isolation. While direct connections to STEM teacher leadership identity were not always explicit, a majority of MTFs described meaningful impacts that these communities had on them related to

STEM instruction or leadership. For instance, some MTFs appreciated being able to strongly identify and bond with their cohort, especially when facing difficult coursework in the project. MTFs further described relationships in their cohort as supportive and open to collaborating and sharing ideas and resources. Mx. Cox viewed their cohort as an especially valuable resource because of the lack of STEM teachers with whom they can collaborate at their own school. Indeed, for multiple MTFs, the cohort provided a sense of security—they have peers to whom they can reach out for support at any time. Moreover, as a result of their cohort's resource and idea sharing, MTFs incorporated new STEM materials into their classrooms or started STEM nights in their communities that they otherwise might not have known existed or felt inclined to try. The utilization of shared resources from the MTFs' cohort in their own settings seems to suggest that MTFs experienced opportunities to develop their motivation, interest, and self-efficacy in integrated STEM teaching and/or leadership if not also in additional dimensions of MTFs' STEM teacher (leader) identity.

MTFs' access to communities of practice also expanded through attending or presenting at conferences, such as regional conferences for Noyce, the National Association of Teachers of Science, the Nebraska Association of Teachers of Mathematics, and the Nebraska Educational Technology Association. For most MTFs, these conferences stood out as key experiences in their second year of the project. NebraskaSTEM personnel shared that some MTFs were more inclined to present together with others from the NebraskaSTEM cohort. MTFs expressed similar sentiments in their interviews: some reported feeling intimidated by the conference or nervous about sharing what they learned at the conference with their colleagues. However, MTFs enjoyed connecting with other people at the conference and seeing different ways STEM has been integrated into classrooms. For Mx. Peterson, the Noyce conference provided them with an opportunity to network with other teachers from similar teaching contexts and therefore more similar experiences than can sometimes be found in their cohort. Thus, networking has the potential to decrease MTFs' feelings of isolation and support MTFs' self-efficacy and interest in STEM teacher leadership.

7 | CONCLUSIONS AND IMPLICATIONS

A major goal of the project was to support teachers' content, pedagogical, and technological knowledge for teaching STEM because such knowledge and expertise are important for STEM teacher leadership and professional identity development (El Nagdi et al., 2018). To earn their master's degree, MTFs were enrolled in several courses designed to develop MTFs' knowledge for teaching integrated STEM in collaborative environments. Our findings suggest the coursework impacted MTFs' competence, interest, and performance as integrated STEM learners, as well as MTFs' self-efficacy, perceptions on how to teach integrated STEM, and self-image as integrated STEM teachers. Specifically, MTFs seemed to develop integrated STEM learner identities (often competence) in tandem with integrated STEM teacher identities (often self-efficacy). Notably, several MTFs expressed increased self-efficacy with respect to various aspects of their STEM teaching, and administrators and colleagues expressed recognition of MTFs as more confident experts in STEM and, thus, viewed MTFs as stronger STEM teacher leaders. Based on this evidence, we posit that coursework from the project supported the simultaneous development of stronger STEM learner and STEM teacher identities in MTFs, which may be precursors to developing STEM teacher leadership identities.

For some MTFs, enrollment in the project in and of itself supported increased recognition as STEM teacher leaders. To be admitted into the project, an administrator at each MTF's school needed to commit to providing support for them as a teacher leader. Hence, administrators were aware of the role MTFs were expected to play in their schools as teacher leaders. Although uncommon in this cohort, one MTF did discuss how turnover in administrators negatively impacted their ability to act as a teacher leader within their school. Thus, good working relationships are key to the work of teacher leaders (Napolitano et al., 2023; Wenner & Campbell, 2017). This implication aligns with findings from Pineda-Báez et al.'s (2020) cross-country study which found principals to be important in empowering teacher leaders to act.

These results imply projects seeking to support STEM teacher leadership identity development in elementary settings should provide coursework that supports competence, performance, and interest in integrated STEM. Our results reinforce other research studies suggesting a strong STEM learner identity is likely a necessary precursor for elementary teachers to integrate STEM within local curricula and impact STEM education on a broader scale beyond their own classrooms (El Nagdi et al., 2018; Holincheck & Galanti, 2023; Napolitano et al., 2023). Moreover, coursework can lead to meaningful changes in teachers' pedagogical practices. One challenge integrated STEM teachers face is shifting their instructional role to that of a facilitator, student-centered instructor (Leung, 2023). These results suggest teachers who experience student-centered, integrated STEM learning activities as students may be more likely to implement such activities in their classrooms. In this study, several MTFs described shifts in their self-images as teachers and efforts to use more student-centered practices. Thus, instructors of integrated STEM teacher preparation courses should use student-centered teaching methods to support teachers in adopting similar practices.

Significant to the coursework's impact, and an impactful project component in its own right, was the cohort model, which supported the development of a new community of practice. MTFs shared that they developed strong group bonds and used the group to complete coursework and communicate ideas that supported their teacher leadership work, especially in the first year of the project. In the second year, MTFs reported using this community less frequently but still had access to one another as needed. Some MTFs attributed the community to decreased feelings of isolation, which may have been connected to their motivation, interest, and self-efficacy surrounding integrated STEM teaching and/or leadership. Furthermore, the community seemed to support MTFs' willingness to engage in networking opportunities, which consequently impacted MTFs' self-efficacy and interest in STEM teacher leadership. This work implies professional development should explicitly foster communities of practice by creating cohorts of teachers from similar contexts who can identify with one another. This connects to Wenner and Campbell's (2018) emphasis on the importance of situating teacher leadership within communities of practice, which are critical places for MTFs to develop their teacher leadership identities and expand their repertoires by performing acts associated with teacher leadership. Membership in multiple communities of practice may present more opportunities for MTFs to develop self-efficacy and interest in STEM teacher leadership.

Holistically, the project supported MTFs' self-efficacy and interest as STEM teacher leaders to advocate for integrated STEM. We found evidence suggesting that increased knowledge of current research on STEM teaching practices supports MTFs' self-efficacy for STEM teacher leader advocacy. Similarly, Velasco et al. (2022) found STEM teacher leaders' advocacy self-efficacy was developed and sustained through participation in professional development of policy knowledge and advocacy activities. Given that MTFs had numerous opportunities to expand their knowledge of policy and activities through coursework (including the rural education course) and their cohort, we echo Velasco et al.'s (2022) sentiments toward offering opportunities for STEM teacher leaders to develop STEM advocacy knowledge and skills.

NebraskaSTEM is one example of a project designed to develop STEM teacher leaders. The project's structures and attention to building a professional community among the participants were key to the development of STEM teacher leadership identity. Moreover, it is important to note that NebraskaSTEM offered several incentives to support MTFs to take advantage of opportunities that would ultimately enhance their professional identity, including earning a master's degree, stipends, and funding for STEM initiatives and travel to conferences. Notably, challenging courses intentionally provided opportunities for participants to bond as a cohort while improving their knowledge and subsequently increased many MTFs' STEM learner and STEM teacher identities. NebraskaSTEM aimed to develop MTFs' knowledge and appreciation for their schools as complex systems in which MTFs could position themselves as STEM teacher leaders. Future professional development projects can benefit from similar foci when seeking to develop and support STEM teacher leaders.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Kelsey Quaisley https://orcid.org/0000-0003-3678-4559
Wendy M. Smith https://orcid.org/0000-0003-4848-4377

REFERENCES

Barrett, N., Cowen, J., Toma, E., & Troske, S. (2015). Working with what they have: Professional development as a reform strategy in rural schools. *Journal of Research in Rural Education*, *30*(10), 1–18.

Barth, S., Criswell, B., Smith, W. M., & Rushton, G. (2024). Modeling how professional development interacts with teacher leaders' outcome expectancies and school environment perceptions. *International Journal of Leadership in Education*, 1–25. https://doi.org/10.1080/13603124.2024.2307877

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11). National Academies Press.

Campbell, T., Wenner, J. A., Brandon, L., & Waszkelewicz, M. (2022). A community of practice model as a theoretical perspective for teacher leadership. *International Journal of Leadership in Education*, *25*(2), 173–196. https://doi.org/10.1080/13603124.2019.1643500

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. https://doi.org/10.1002/tea.20237

Chiu, A., Price, C. A., & Ovrahim, E. (2015). Supporting elementary and middle school STEM education at the whole school level: A review of the literature [conference presentation]. In *NARST 2015 annual conference*. NARST.

Corp, A., Fields, M., & Naizer, G. (2020). Elementary STEM teacher education: Recent practices to prepare general elementary teachers for STEM. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *The handbook of research on STEM education* (pp. 337–348). Routledge. https://doi.org/10.4324/9780429021381-32

Creswell, J., & Poth, C. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). SAGE.

Criswell, B., Smith, W. M., Yow, J. A., Lotter, C., Ahrens, S., Rushton, G., Gonczi, A., Polizzi, S. J., & Barth, S. (2022). Viewing STEM teacher leadership through a communities-of-practice lens. In L. Manier, T. T. York, & B. Callinger (Eds.), *Research in practice: Preparing and retaining K–12 STEM teachers in high-need school districts* (pp. 355–395). American Association for the Advancement of Science. https://doi.org/10.1126/aaas.add8007

Dabney, K. P., Chakraverty, D., & Tai, R. H. (2013). The association of family influence and initial interest in science. *Science Education*, *97*(3), 395–409. https://doi.org/10.1002/sce.21060

El Nagdi, M., Leammukda, F., & Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education*, *5*(36), 1–13. https://doi.org/10.1186/s40594-018-0136-1

Galanti, T. M., & Holincheck, N. (2022). Beyond content and curriculum in elementary classrooms: Conceptualizing the cultivation of integrated STEM teacher identity. *International Journal of STEM Education*, *9*(43), 1–10. https://doi.org/10.1186/s40594-022-00358-8

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research*, *6*(1), 11–29. https://doi.org/10.7771/2157-9288.1129

Hanna, F., Oostdam, R., Severiens, S. E., & Zijlstra, B. J. (2020). Assessing the professional identity of primary student teachers: Design and validation of the teacher identity measurement scale. *Studies in Educational Evaluation*, *64*, 100822. https://doi.org/10.1016/j.stueduc.2019.100822

Harbin, J., & Newton, J. (2013). Do perceptions and practices align? Case studies in intermediate elementary mathematics. *Education*, *133*(4), 538–543.

Holincheck, N., & Galanti, T. M. (2023). Applying a model of integrated STEM teacher identity to understand change in elementary teachers' STEM self-efficacy and career awareness. *School Science and Mathematics*, *123*, 234–248. https://doi.org/10.1111/ssm.12610

Hopkins, M., Spillane, J. P., Jakopovic, P., & Heaton, R. M. (2013). Infrastructure redesign and instructional reform in mathematics: Formal structure and teacher leadership. *The Elementary School Journal*, *114*, 200–224. https://doi.org/10.1086/671935

Huggins, K. S., Lesseig, K., & Rhodes, H. (2017). Rethinking teacher leader development: A study of early career mathematics teachers. *International Journal of Teacher Leadership*, *8*(2), 28–48.

Hughes, P., Swars Auslander, S., Stinson, D. W., & Fortner, C. K. (2019). Elementary teachers' mathematical beliefs and mathematics anxiety: How do they shape instructional practices? *School Science and Mathematics*, *119*(4), 213–222. https://doi.org/10.1111/ssm.12329

Leung, W. M. V. (2023). STEM education in early years: Challenges and opportunities in changing teachers' pedagogical strategies. *Education Sciences*, *13*(5), 490. https://doi.org/10.3390/educsci13050490

Luo, T., & So, W. W. M. (2023). Elementary students' perceptions of STEM professionals. *International Journal of Technology and Design Education*, *33*, 1369–1388. https://doi.org/10.1007/s10798-022-09791-w

Maiorca, C., & Mohr-Schroeder, M. J. (2020). Elementary preservice teachers' integration of engineering into STEM lesson plans. *School Science and Mathematics*, *120*(7), 402–412. https://doi.org/10.1111/ssm.12433

Moore, T., Stohlmann, M., Wang, H., Tank, K., Glancy, A., & Roehrig, G. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35–60). Purdue University Press.

Napolitano, K., Gunning, A. M., Marrero, M. E., & Nitecki, E. (2023). Developing and sustaining elementary STEM teacher leadership identities. *Global Education Review*, *10*(4), 37–55. https://ger.mercy.edu/index.php/ger/article/view/648

National Research Council (NRC). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

National Science Board. (2024). Talent is the treasure: Who are we leaving on the bench? Report #: NSB-2024-11 [Policy brief]. https://www.nsf.gov/nsb/sei/

Pew Research Center. (2021, April 1). STEM jobs see uneven progress in increasing gender, racial and ethnic diversity. https://www.pewresearch.org/science/2021/04/01/stem-jobs-see-uneven-progress-in-increasing-gender-racial-and-ethnic-diversity/

Pineda-Báez, C., Bauman, C., & Andrews, D. (2020). Empowering teacher leadership: A cross-country study. *International Journal of Leadership in Education*, *23*(4), 388–414. https://doi.org/10.1080/13603124.2018.1543804

Quaisley, K., Funk, R., Smith, W. M., Criswell, B., & Hutchinson, A. (2023). From becoming to being: How STEM teachers develop leadership identities. *International Journal of Leadership in Education*, 1–28. https://doi.org/10.1080/13603124.2023.2292161

Saldaña, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). Sage. https://doi.org/10.1108/QROM-08-2016-1408

Schaeffer, M. W., Rozek, C. S., Maloney, E. A., Berkowitz, T., Levine, S. C., & Beilock, S. L. (2020). Elementary school teachers' math anxiety and students' math learning: A large-scale replication. *Developmental Science*, *24*(4), 1–6. https://doi.org/10.1111/desc.13080

Sinha, S., & Hanuscin, D. L. (2017). Development of teacher leadership identity: A multiple case study. *Teaching and Teacher Education*, *63*, 356–371. https://doi.org/10.1016/j.tate.2017.01.004

Sutton, J. T., Mitchell, A., & Espel, E. (2015). Nebraska statewide mathematics and science partnership program needs assessment. Report prepared for the Nebraska Department of Education.

Velasco, R. C. L., Hite, R., & Milbourne, J. (2022). Exploring advocacy self-efficacy among K-12 STEM teacher leaders. *International Journal of Science and Mathematics Education*, *20*, 435–457. https://doi.org/10.1007/s10763-021-10176-z

Wenner, J. A., & Campbell, T. (2017). The theoretical and empirical basis of teacher leadership: A review of the literature. *Review of Educational Research*, *87*, 134–171. https://doi.org/10.3102/0034654316653478

Wenner, J. A., & Campbell, T. (2018). Thick and thin: Variations in teacher leader identity. *International Journal of Teacher Leadership*, *9*(2), 5–21.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Sage.

Yow, J. A., Criswell, B., Lotter, C., Smith, W. M., Rushton, G., Adams, P., Ahrens, S., & Hutchinson, A. (2021). Program attributes for developing and supporting STEM teacher leaders. *International Journal of Leadership in Education*, 1–24. https://doi.org/10.1080/13603124.2021.2006794

Zhou, X., Shu, L., Xu, Z., & Padrón, Y. (2023). The effect of professional development on inservice STEM teachers' self-efficacy: A meta-analysis of experimental studies. *International Journal of STEM Education*, *10*(37), 1–20. https://doi.org/10.1186/s40594-023-00422-x

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