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A cross-case analysis of rural robotics teacher leaders' identity development

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As educational robotics (ER) becomes an increasingly popular extracurricular opportunity for K-12 STEM learning, researchers continue to explore effective learning environments and teaching approaches for this integrated form of instruction. However, limited research has examined the experiences of rural educators implementing robotics programs or how these programs contribute to rural teacher leadership development. This qualitative study examines the experiences of rural robotics teachers (RRTs) and the development of their identities as rural STEM teacher leaders. Guided by the rural teacher leadership in the science and mathematics framework, the findings highlight leadership skills that helped RRTs pioneer ER programs in rural schools. The results offer insights into how rural schools can support teacher leadership development in STEM, particularly through integrated, innovative STEM learning approaches. Implications from this study strengthen the support for the rural teacher leadership framework in other STEM content areas.

KEYWORDS

rural, STEM education, robotics, K-12, teacher leader identity

Introduction

The United States has a rapidly growing number of STEM job opportunities in nearly all areas of the country, including rural communities (Peterson et al., 2015; Rice et al., 2013). Though rural youth are less likely to take advanced mathematics courses and have career counseling to prepare them for STEM fields, their mathematics and science achievement and interest are comparable to their non-rural peers (Crain and Webber, 2021; Griffin et al., 2011; Irvin et al., 2017; Meece et al., 2013; Williams, 2005; Zuniga et al., 2005). Despite STEM job availability, students often pursue non-STEM careers (President's Council of Advisors on Science and Technology, 2012). Thus, the challenge of preparing rural youth for such job opportunities that are often available in their community entails addressing both STEM preparation and interest (Harris and Hodges, 2018; Lakin et al., 2021). To that end, the use of educational robotics (ER) continues evolving in K-12 STEM education (Evripidou et al., 2020; Toh et al., 2016) and may be effective in enhancing STEM preparation and interest among rural youth. Indeed, formal and informal learning through ER enriches the educational environment and impacts student interest, engagement, and academic achievement (Anwar et al., 2019). Additionally, students have greater mathematics and science achievement when involved with ER competitions (Chung et al., 2014), and robotics plays an active role in the education of STEM subjects, such as mathematics (Zhong and Xia, 2020).

However, educational inequities in the United States, such as access to qualified educators and training, inhibit the provision of high-quality STEM experiences, like ER, for underserved and underrepresented populations, including youth in rural areas and from Hispanic

backgrounds (Flores, 2011; Harris and Hodges, 2018; Passel et al., 2022; Schina et al., 2021). Additional factors known to inhibit ER use include limited technology integration (El-Hamamsy et al., 2021) as well as the absence of high school curriculum and STEM teacher certification programs (Goode and Margolis, 2011), and the provision of professional development for teachers in STEM content (National Academies of Sciences, Engineering, and Medicine, 2025; Papadakis et al., 2021). El-Hamamsy et al. (2021) further posited that although ER has a lot to offer students, "this comes at the price of limited outreach, since it relies on having both flexibility in the curriculum and innovative teachers and pioneers" (p. 5078). Therefore, it can be argued that rural educators who use ER for STEM instruction, both formally and informally, are teacher leaders and play a vital role in providing and integrating ER in rural schools (Chevalier et al., 2016).

While prior literature on teacher leader identity development is general (Sinha and Hanuscin, 2017) or considers STEM fields as one context (Hite and Melbourne, 2018; Yow et al., 2021), many advocate for further study within more specific content or fields, including rural settings (Lotter et al., 2020). Additionally, empirical data regarding the facilitation of ER by rural teachers is limited, and studies that specifically investigate the identity development of these rural robotics teachers (RRTs) have yet to be explored. To answer that call, our study focuses on rural STEM teacher leadership identity development for using ER in rural schools. Rural teachers may have little to no formal knowledge of and skill development in ER, and scarce availability of content-specific training opportunities. Thus, an important question is how do rural educators develop their identity as rural robotics teacher leaders? Nonetheless, we also view rural educators who develop their identity as teacher leaders as those with the influential capacity to impact their entire school, community, and profession (Wenner and Campbell, 2017) in both formal and informal STEM settings. This ideation of rural teacher leadership originates from the isolation that rural schools experience, their central role in the community, and their need to draw on school-wide and community support for program and activity offerings (Schafft, 2016), the impact ER has on discipline-specific achievement and learning outcomes (Chung et al., 2014; Evripidou et al., 2020), and the formal and informal STEM knowledge and skill development that occurs within and outside classroom instruction through competitions with ER (Nelson, 2014; Nugent et al., 2014).

Educational robotics

Educational robotics is a highly popular approach for developing and integrating STEM knowledge, skill, and interest in formal classroom instruction through course offerings and curriculum, and in informal competitive settings (Anwar et al., 2019; Chung et al., 2014). As an informal extracurricular STEM activity, competitive ER combines STEM knowledge in multiple disciplines, such as computer science, engineering, physics, and mathematics, in a project-based team approach to solving various design challenges (Caron, 2010). Competitive ER can improve motivation for computer science learning (Bazylev et al., 2014), mathematics and science achievement (Chung et al., 2021), critical thinking and collaboration (Menekse et al., 2017), and interest in technical disciplines (Matson et al., 2004). A recent systematic review analyzed 147 published studies from 2000 to 2018 in ER and surmised that much of the research on ER varies in levels and scope regarding the areas of general effectiveness, learning and transfer of skills, creativity and motivation, diversity and broadening participation, and teachers' professional development (Anwar et al., 2019). However, some studies of ER have reported no changes in learning (Benitti, 2012; Xia and Zhong, 2018).

These mixed results may be apparent because of differences in educator preparation for implementing ER combined with largely non-standardized curriculum, materials, and resources that may make ER not conducive to learning in some contexts (Dwivedi et al., 2021). Still, a variety of national and international competitive ER programs exist [e.g., Boosting Engineering, Science and Technology (BEST), For Inspiration and Recognition in Science and Technology (FIRST), VEX Robotics], which offer training and materials for their game events and implementation of ER within schools. Nonetheless, it is up to those facilitating ER programs to select and implement an ER program in a manner consistent with their school's characteristics, philosophies, and technology resources (Johnson and Londt, 2010). Relatedly, Toh et al. (2016) conducted a review focusing on the use of robotics in education and found that, while educators and parents alike saw the potential for STEM learning through ER, educators were less confident in their use of robotics for teaching. Furthermore, Xia and Zhong (2018) found a variety of instructional interventions in ER research, but these were limited in addressing the nuances (e.g., multidisciplinary, hands-on experiences, integration of content) of robotics curricula. In a side-by-side review of existing literature with robot-based learning activities, platforms, and toolkits involving physics and mathematics, Karim et al. (2015) identified the development of robotics-specific, pedagogical training modules for teacher learning and curriculum development as one of the important issues needed in ER research for teachers to be able to respond to student inquiries in this content area.

While studies are exploring ER in teaching and learning, research in rural contexts is limited, program-specific, or focuses on only formal classroom learning and does not consider the informal learning settings of competitive ER. However, Matson et al. (2004) studied the effects of a robotics road show on the STEM interest of K–6th-grade students in rural Kansas and found the program extremely popular for building engagement and basic knowledge of robotics among rural, underserved communities. Additional research has also investigated the outcomes of rural teacher participation in various professional development and partnership opportunities, finding positive benefits in teachers' culturally responsive teacher self-efficacy and computational thinking (Leonard et al., 2018), as well as the development of support systems for increasing the use of ER (Maximova and Kim, 2021).

Rural STEM teacher leadership framework

Recent research focuses on the development of teacher leadership identity (Criswell et al., 2018; Smylie and Eckert, 2018; Sparks, 2009). While a variety of leadership roles exist within schools, a teacher leader is a "teacher who maintains K-12 classroom-based teaching responsibilities, while also taking on leadership responsibilities outside of the classroom" (Wenner and Campbell, 2017, p. 7). According to Sparks (2009), teacher leadership identity development is essential to high-quality teaching and learning for all students. Moreover, teacher leadership identity is an expression of habits in

thinking and acting that result from repeated practice of core tasks (Sparks, 2009). However, teachers may take several different unique paths to develop as a leader, and this depends on a multitude of factors such as one's priorities, school context, and experiences (Sinha and Hanuscin, 2017; Wenner and Campbell, 2017; York-Barr and Duke, 2004; Yow et al., 2021). Within STEM, researchers have introduced several frameworks describing teacher leadership and the process by which it develops (Gillespie, 2015; Hite and Milbourne, 2018; Yow et al., 2021). In becoming a K-12 STEM teacher leader, educators progress through different participation experiences (Hite and Milbourne, 2018) and career stages within teaching (Gillespie, 2015). To facilitate such development, there are several programs designed to foster STEM teacher leadership, and a review by Yow et al. (2021) found that all include varying degrees of professional development, graduate coursework, networking, mentoring, and knowledge sharing.

As a starting point for investigating rural STEM teacher leadership for ER, our study draws on the rural teacher leadership in the science and mathematics framework (Lotter et al., 2020). While this framework does not explicitly focus on ER, it is one of the few, if not only, frameworks on rural teacher leadership and within STEM, which includes multiple disciplines relevant to ER (i.e., science and mathematics). The rural teacher leadership in science and mathematics framework was developed from the more general teacher leader model standards (TLMS) (Lotter et al., 2020; Teacher Leadership Exploratory Consortium, 2011), utilizing six of the seven domains Lotter et al. (2020) deemed applicable to the rural context. Lotter et al. (2020) further expanded the framework's six domains by providing three important recommended foci for rural teacher leadership: the significance of relationships with students, the significance of relationships with community members, and the influence of strong resource networks. Table 1 contains information describing each of the main domains and the three additional focal points, which include examining the potential importance of building such relationships with students, community members, and strong resource networks. Specifically, and based on prior research recommendations to include a greater focus on content-specific knowledge and skills (Berg et al., 2014), modifications to Domain III of the TLMS were made in the development of the rural teacher leadership framework to coincide with the focus on science and mathematics content. Specifically, Domain III included the phrase *tied to content* (Lotter et al., 2020). As content knowledge and pedagogical approaches develop, rural teacher leaders feel driven to build strong teacher–student relationships, provide educational opportunities for students, encourage student success, and build community connections.

TABLE 1 Rural teacher leadership in science and mathematics framework domains.

Domain	Description
Foster a Collaborative Culture	Teacher Leaders' (TLs) work with colleagues, building trust and collegiality to promote instructional improvements.
Assessing and Using Research to Improve Practice and Student Learning	TLs understand the importance of new knowledge, systematic inquiry, and the responsibility to communicate learnings to a larger audience.
Promote Professional Learning for Continuous Improvement Tied to Content	TLs understand the constant evolution of teaching and learning and the need to remain current in the practice and content of teaching.
Facilitating Improvements in Instruction and Student Learning	TLs reflect to improve student learning and develop a curriculum that addresses issues of equity and diversity.
Improving Outreach and Collaboration with Families and Community	TLs work with families and utilize the expertise in their communities to impact student learning.
Advocating for Student Learning/ Profession	TLs understand policy and advocate for students and teachers to promote student learning.
*Understanding the significance of relationships with students	TLs understand the importance of relationships that meet not only students' academic but also personal needs and serve as an advocate both in and outside the classroom.
*Understanding the significance of relationships with community members	TLs understand the value of involving the community to enhance instruction and learning.
*Understanding the importance of strong resource networks that can provide both financial and affective supports	TLs work within their formal and informal networks to create opportunities and experiences.

*Three additional recommendations outlined in the teacher leadership framework (Lotter et al., 2020).

The current study

As mentioned, further research is needed to understand rural teacher leadership identity development in science and mathematics education (Lotter et al., 2020; Wenner and Campbell, 2017), including ER that is used in both formal classroom settings and informal extracurricular competitions. The advent of integrated STEM learning and ER in these formal and informal settings further broadens additional opportunities for rural teachers to become leaders and addresses the need of rural teacher training. However, research shows that rural schools have limited instructional resources, opportunities to engage students in high-level science and mathematics content, and opportunities for professional development for rural teachers (Lotter et al., 2020). To provide rural students with successful formal and informal STEM experiences using ER, developing the identity of rural teacher leaders and understanding the process by which this may occur is necessary. Thus, our research employed a case study design to examine the experiences of four teachers who successfully initiated robotics teaching and learning, both through formal classroom instruction and within informal, extracurricular ER competitions in rural, low-income, Hispanic-serving secondary schools. Utilizing the rural teacher leadership framework in mathematics and science and a qualitative cross-case analysis approach, we focus on participating teachers' rural robotics teacher identity (RRTI) development *via* the following research questions:

- How does the rural teacher leadership framework apply and expand to competitive robotics programs when used in both formal and informal settings?
- What experiences shape RRTI development?

Methods

Qualitative research procedurally investigates social occurrences through contrast and comparison of objects under study (Miles and Huberman, 1984). To investigate "complex social units consisting of multiple variables of potential importance" (Merriam, 2009, p. 50), this study utilized a cross-case analysis of RRTs' implementation of competitive robotics programs in rural, low-income, Hispanic-serving secondary schools. A case study approach (Yin, 2002, 2018) was selected to explore the contemporary phenomenon of RRT leader identity development within the complex, loosely bounded context of blended formal and informal ER facilitation in rural schools. Cross-case analysis was particularly suited to the research objectives, as it enabled the systematic comparison of multiple teachers' experiences, highlighting both shared patterns and contextual differences in their development as robotics teacher leaders. This approach facilitated a nuanced understanding of how rural teachers navigate the unique challenges of implementing ER, engage as change agents within their communities (Lee and Chavis, 2011), and build capacity for STEM learning. By comparing cases, this study identified commonalities and divergences in teachers' identity development processes and their facilitation of ER across formal classrooms and informal competitive settings in rural contexts.

Participants in our study included four competition-successful rural robotics secondary school teachers in three rural-remote locations and one town-remote location (National Center for Education Statistics, 2022). Upon approval to conduct this study by an Institutional Review Board responsible for ethical considerations in conducting human subjects research, participating teachers were chosen specifically for their affiliation with schools that largely serve underrepresented (Hispanic) and underserved (rural) students and their record of success in robotics competitions against schools 10 times their size. In that regard, these participants were viewed as rural teacher leaders, individuals who improved learning in their schools by developing an informal opportunity and curriculum that addressed inequities for diverse populations in STEM (Lotter et al., 2020). To provide further context for the participants in this study, demographic information for each participant is listed in Table 2. Within the teachers' demographic information, attention should be drawn to the teachers' roles within the school and their teacher certification qualifications. This provides further insight into the rural context and how rural teachers often teach multiple subjects or subjects that are out of their content expertise (National Academies of Sciences, Engineering, and Medicine, 2025). To elaborate further on the rural school context in which these teachers work, demographic information for the participant schools is listed in Table 3.

Data sources involved a 1-h-long individual interview with each participant. The interviews were then transcribed and analyzed in MAXQDA using a thematic analysis framework (Braun and Clarke, 2006). Data analysis consisted of two independent researchers coding for initial theme development. After primary coding, the two researchers collaborated on themes to determine commonalities and differences. A thematic codebook was then created, followed by a second round of coding and peer debrief (Creswell and Creswell, 2023) to verify themes and code assignments. Preliminary themes and codes are shown in Table 4. Based on the themes that emerged, we recognized a distinct connection between participating in RRT experiences and the rural teacher leadership framework (Lotter et al., 2020). Furthermore, our paper aims to highlight the alignment of TLMS domains with specific instances of the robotics teachers' informal teaching and leadership experiences.

Several measures were undertaken to address the trustworthiness and credibility of this study. First, after the conclusion of each interview and for member checking validation, transcripts were sent back to participants for review and confirmation of interpretations, and further questions were subsequently asked for clarity of ideas, concepts, and theme development. Pseudonyms were used for all participants, and these fake names, along with time stamps, were used

TABLE 2 Demographic RRT data.

Pseudonym	Role	School (pseudonym)	Gender, race/ ethnicity	Certification	Total years teaching	Total years teaching robotics
James Williams	Part-time robotics teacher	Morado and Corazon	Male, white/ Caucasian	Industrial technology, 7–12	38	8
John Smith	Principal	Blauzweig	Male, white/ Caucasian	Science 7-12, Technology Education 7-12, Principal	12	10
Ricardo Lucero	Culinary arts	Morado	Male, Hispanic	Culinary arts 7–12	10	10
Steve Brown	Robotics teacher	Sunshine	Male, white/ Caucasian	Computer Science 7–12, History 7–12, Mathematics 6-8	26	9

TABLE 3 Demographic school data.

Name	Rural designation	Hispanic serving	Low-income	Total K-12 school population	Percent student ethnicity		
					White	Hispanic	Other
Blauzweig	Rural-remote		X	250	87.2	8.8	4
Corazon	Rural-remote	X	X	1,153	8	90.5	1.5
Morado	Town-remote	X	X	209	6.1	93.4	0.5
Sunshine	Rural-remote	X	X	591	41.3	56.5	2.2

TABLE 4 Preliminary themes and codes.

Higher-level code	Secondary code	Participant example excerpts
Components of robotics program	*How it started*	"And we just learned through whatever we started to do, half the time because it was in our area. We are very, we have a lot of heart, we have a lot of grit, and we have strong work ethic" (Ricardo)
	Success	"So a lot of the success here (Blauzweig) comes from home life. And parents having high expectations for their children, as opposed to when I was in Corazon, they [the students] came for me, and because I expected more of them. I so ended up filling some of that parent role that is filled here in Blauzweig, just because of the culture of Blauzweig. And so I feel like that, 'why are we successful' is relationships, building solid relationships with the students building their trust, like two years, and they followed me right into this thing" (John)
	Rural vs. larger school comparisons	"So, I have talked to teachers from large schools, and they do not understand small schools. So, I've talked to a teacher once, and he was telling me how they did their CAD, that all their kids have computers. …. And Dell gave every kid in the program, a free computer. Whereas my program, and at school, we have one computer, and that was to take roll on. And that's all it was for, you know, so they do not understand what it's like to be in a small school" (James)
Robotics teacher	*Knowledge of STEM*	"So STEM and STEM related careers reach every industry, food service, health wise, agriculture. And those are all things that people need. And so I do see that it's going to make its way to our area, its just a matter of time." (Ricardo)
	Passion	"And you see kids faces when they win, our robots, when they win, or they do something that they have never done before. If the robot also does something it has never done before…it is like bang, you know, your eyes light up, and that's the thrill I get out of it. When I see those kids eyes light up, then I realized that I've made a difference." (James)
	Support	"We've all had a year one. And that's what continued to motivate me as a teacher to help other teachers because in the inception of it, in the beginning it's very scary…" (Ricardo)
	Student relationships	"In a rural school, you have got to build those relationships. Without the relationships, the kids will not come into the program." (John)
Student	*Recruitment*	"So, after I tapped them on the shoulder, brought them into the program that had the right stuff to make it look like an actual robot. I picked them out based on the skills that I saw from them in class. Could you reason critically? How did you see the world? Are you a problem solver? Do you give up?" (John)
	Motivation	"And we did not advance to the regional meet. But then we had another meeting. And they were like we would like to continue working on these things. So what they have done is they developed their own project on intake systems and logic systems and they have also come together as a group, and they really want to get better at computer aided design." (Ricardo)
	Interest levels	"So everybody's assigned something to do in the class, I try to get them interested in something. One student got interest in the CAD stuff, so all they want to do is play, work on the computer do CAD. He really did not want anything to do with robotics." (James)
School system	*Administration support*	"It was principal driven. She had seen it in some conferences that she had gone to and thought it'd be a good thing for, our school to be involved. Also felt like she thought it would be a good outlet for her children." (James)
	Funding opportunities	"So both Corazon and here in Blauzweig… the administrations were very supportive. In Corazon's, they basically just poured money into my program, because I was seeking grants. So for every dollar in a grant that I got, they basically matched me on budget. So I pulled in $5,000, in grants, they gave me $5,000 in money that I could I could just bolster the program. "(John)
	Outreach	"We've done a few things. We've had the recycling drive, canned food drive, and other things like that…And so that gives the kids a little bit of give back to the community. Community service drive, you know, what can we do to help? We also try to help out with the robotics program at the junior high." (Steve)
	Community support	"And the community has supported us just like we were football actually. Then the Valero plant right up there. And they are a huge part of this school. They've funding a lot of things and they have given us three grants to help in the first two years to get it started" (Steve)
	Parent support	"I had a young lady, her parents were from Mexico. And they thought that she needed to get married, have children. That was their, their goal for her. She joined the robotics team. They did not want that." (James) "And so our students did fundraise with their parents' companies, like this small automobile organization here, some of students have parents that have trucking companies. They also donated a couple of $100. So just to know that the diversity, and they see that the impact, positively, that it's making for their students and their demeanor and character even at home. They're like, if my kids excited about it, I want to support." (Ricardo)

in the audit trail process so that specific codes that corresponded to the developed themes could be traced directly back to the data source within the interview transcript. Additionally, the use of peer debriefing between two independent coders of the research team contributed to the credibility and trustworthiness of the study. Upon completion of code assignment and theme development, confirmation of code assignment and themes were also verified by a third independent member of the research team who was not involved in the coding process. Although the data analyzed for this study was limited to interviews, triangulation was achieved through themes that only

emerged from codes that were sourced from all participants. Themes were not included in the results if they were not generated from codes that originated from data from every participant.

Results

Findings are organized by the TLMS framework domains to directly address RQ1, illustrating how RRTs' experiences map onto and expand the framework. Within each domain, we describe specific teacher experiences that shaped their development as RRT leaders (RQ2). Thematic analysis revealed that RRTs' experiences directly aligned with each of the domains, focusing on their leadership roles and the development of collaborations, advancing student learning, and strengthening networks within the schools and communities. The following results reveal specific instances of teacher experiences and how they can be linked to the evolving rural teacher leadership framework (Lotter et al., 2020).

For the TLMS Domain I, *fostering a collaborative culture*, several RRTs focused on discussing their experiences with each other and building a positive professional learning community together. The major theme that emerged in connection with the domain's focus on collaboration with colleagues is the ways in which RRTs across the state utilized each other to improve their programs and build a network of support over time. One teacher expressed:

> We met at a clinic this summer. And we sat down and just talked when they could not get parts. So, she reached out. And so, we were like, as a team, let us do this. Let us, let us interact, interact with them. That's so we would give them… they would ask us questions. We just answered and we have brought in, I've brought in teachers into our program, and they sit with me all day, and watch what we did as far as the robotics. So as a teacher, you need to reach out to these other schools. I know Smith has done it with schools… have come in and sat down with him. The beginning of the year, we had problems with our arm. Okay, I went out to Smith, I called him and said, Hey, got a problem. Could you look at our robot arm? And so I went over there and spent an hour with him. And we figured that out (James Williams).

Table 5 provides additional participating RRT leaders' example excerpts associated with the *fostering a collaborative culture* domain of the TLMS framework.

For the TLMS Domain II, *assessing and using research to improve practice and student learning*, multiple rural teachers emphasized the importance of a continuous learning and teaching approach in the field of ER. Specifically, a major topic of discussion focused on robotics programs and how much they can and will change over time. For example, a teacher mentioned:

> And so having these different interests can grow a program, but then you also need to start pulling in mentors outside to help grow your program. So, I do not know very much about computer aided drafting, I've just self-taught my things. But we were able to work with [local University], you helped us kind of get our foot in the door to have that thing. And we ended up meeting with Dr. [local University Engineering Faculty]. And he's stepped in and helped us and give us some CAD skills, like my CAD skills run a program

TABLE 5 Transcript excerpts for TLMS domain I.

Domain	Description	Example quotes
Foster a Collaborative Culture	Teacher Leaders' (TLs) work with colleagues, building trust and collegiality to promote instructional improvements	"We met at a clinic this summer. And we sat down and just talked when they could not get parts. So she reached out. And so we were like, as a team, let us do this. Let us, let us interact, interact with them. That's so we would give them… they would ask us questions. We just answered and we have brought in, I've brought in teachers into our program, and they sit with me all day, and watch what we did as far as the robotics. So as a teacher, you need to reach out to these other schools. I know Smith has done it with schools… have come in and sat down with him. The beginning of the year, we had problems with our arm. Okay, I went out to Smith, I called him and said, Hey, got a problem. Could you look at our robot arm? And so I went over there and spent an hour with him. And we figured out that." (James Williams) "We want to help each other to the best of our ability. And it's part of what drives FIRST Robotics. FIRST Robotics main quote, is what? Gracious professionalism. We want to be gracious, we want to be professional. We want to whip your tail when we are up against you. But we'll do everything we can to help you beat us. And okay, there's an old saying in the rodeo world, which is where I come from, originally. And that is me. [Points to his screen saver on his computer screen on his desk. It has a picture of two men tie roping a calf on horseback in competition at the Helium National Center in Helium, TX. One of the men in the picture is Steve] Okay. And that is a Helium Rodeo event. Yeah, that was my nephew. Anyway, there's an old saying, I'm going to do everything I can to beat you. And then I'm going to turn around and help you beat me. We have always been that way in rodeo. So this comes second nature to me. I'm going to do my absolute very best to beat you. And if I can help you beat me, then go for it. Gracious professionalism." (Steve Brown) "So it's just… we have all grown together the last 10 years. And so since that, we have helped to start other programs in the area. We've also encouraged other coaches and people, we have held conferences that we did at the education service center in Helium, conferences that we did at the southern region education service center. And really just kind of put all of our ideas together and try to be an advocate for the FIRST program, because of the robustness that it is, and would offer students." (Ricardo Lucero)

> that kids will never use. It's not an industry standard. But now he's put us with Autodesk Fusion 360. And so I'm like, Okay, now I was able to learn, just watching him teach my kids gave me what I needed to take my past training in Creo and move it over to Fusion. And that helped me and that was perfect. And so now, now maybe he can help us take some of the next steps. And so building some of those, again, stepping outside of your school breaking past your culture barrier" (John Smith).

Table 6 details further utterances from the participant interviews that exemplify this portion of the TLMS domain.

For the TLMS Domain III, *promoting professional learning for continuous improvement tied to content*, teacher interviews revealed how ongoing learning opportunities are valuable markers in determining where the individual robotics programs are in terms of progress and expertise, as well as teaching progression to benefit student learning and success. A major theme that emerged from these discussions revolved around the continued efforts of teachers to seek out additional learning opportunities to advance their roles as leaders in the educational robotic realm and further their expertise in the STEM field. For example, a teacher discussed:

> So they sent me to a 2 days clinic. And within 3 days of class, I covered everything that I knew in that deal in from that clinic. So we used a lot of research online. I promised myself, every night I would study robotics, through YouTube and the internet for at least an hour a night. Because I'm very competitive. I do not like to put students in a situation where I do not even understand, because then that takes away from them. Because they are very disappointed, because no one knew what was going on. So I just kind of prompt myself, I'd study every night, and some nights, it was five, 6 h, and some nights it was, you know, a couple of hours, but every night I would study through the internet. Just explore what robotics is about where to go and how to do it" (James Williams).

Table 7 contains additional data that extend to the TLMS domain *promoting professional learning for continuous improvement tied to content*.

For the TLMS Domain IV, *facilitating improvements in instruction and student learning*, the robotics teachers talked through the processes of such enhancements in student development. An important element that aligns appropriately with the fourth domain is the teachers' perspectives on the unique spaces that have been built around the robotics programs. Specifically, teacher experiences uncovered instances around equity and diversity directly in relation to student performance and motivation put forth in the programs. For example, a teacher speaks of how such programs and leadership allow students to discover their true passions and how the programs can be structured to embrace student trial and error as a means of success.

> Well, I do my very, very best to find them a job that they will tolerate. Not necessarily that they like or that they are good at but one that they will tolerate. I need you to organize that toolbox. They might tolerate that. They want to be a part of anything else. But they better do what I ask. Every child that I've got that I've ever had will do what I ask or at least try it. The ones that really want to be here, you know, they have got specific jobs and they do everything all the time. But I do have a couple this year that only

TABLE 6 Transcript excerpts for TLMS domain II.

Domain	Description	Example quotes
Assessing and Using Research to Improve Practice and Student Learning	TLs understand the importance of new knowledge, systematic inquiry, and the responsibility to communicate learnings to a larger audience	"Ask for help. Because there's going to be plenty to be had. That's the first thing I would tell you. Do not hesitate to ask for help. Second, research. Which robotics program do you want to be a part of? Do you want to be a part of Vex? Do you want to be a part of BEST? Do you want to be a part of FIRST? What age groups are you going to be doing? That's going to make a difference into where your program goes. I highly recommend you start with FIRST. I've been a part of Vex. I've been a part of BEST. And I've been a part of FIRST. FIRST is by far, in my opinion, the best and most supportive. So then pick. Secondly, if you… if you are brand new, after you have done that, and you ask for help." (Steve Brown) "And so having these different interests can grow a program, but then you also need to start pulling in mentors outside to help grow your program. So I do not know very much about computer aided drafting, I've just self-taught my things. But we were able to work with [local University], you helped us kind of get our foot in the door to have that thing. And we ended up meeting with Dr. [local University Engineering Faculty]. And he's stepped in and helped us and give us some CAD skills, like my CAD skills run a program that kids will never use. It's not an industry standard. But now he's put us with Autodesk Fusion 360. And so I'm like, Okay, now I was able to learn, just watching him teach my kids gave me what I needed to take my past training in Creo and move it over to Fusion. And that helped me and that was perfect. And so now, now maybe he can help us take some of the next steps. And so building some of those, again, stepping outside of your school breaking past your culture barrier." (John Smith) "The robotics is, it's a fun, it's a journey… robotics is the future. It's the autonomous stuff. There's tons of autonomous things that are being put out there. Now we push a button and it runs by itself. You know, even in the technology field, if you want to be a welder, there's, there's the welding side of it. And it's all being automated. And someone's got to fix those machines and someone's got to set those machines up. Someone's got to build those machines. And those are what some of my kids see as a way out. You know, so, we push all of our kids, not unnecessarily to go to college, but to better themselves." (James Williams)

TABLE 7 Transcript excerpts for TLMS domain III.

Domain	Description	Example quotes
Promote Professional Learning for Continuous Improvement Tied to Content	TLs understand the constant evolution of teaching and learning and the need to remain current in the practice and content of teaching	"And we do know that there's now… at that time, earlier on, there was about 14 programs available. Now there's more than 20, robotics programs, best independent programs, online programs, because of COVID. So… but we were still very true to FIRST because its core values. One of them being gracious professionalism, which is something I think everybody needs to know. And so that's one of the hallmarks that resonates with us just continue to improve the program here, regionally with the limited resources that we have. We set goals for ourselves as leaders, and it's not just me, it's all of us together, and all of us to benefit our students, to benefit the workforce, in the future, to benefit innovation, to benefit the core of what math and science are, because you cannot do this without understanding those fundamental skills." (Ricardo Lucero) "So they sent me to a two day clinic. And within three days of class, I covered everything that I knew in that deal in from that clinic. So we used a lot of research online. I promised myself, every night I would study robotics, through YouTube and the internet for at least an hour a night. Because I'm very competitive. I do not like to put students in a situation where I do not even understand, because then that takes away from them. Because they are very disappointed, because no one knew what was going on. So I just kind of prompt myself, I'd study every night, and some nights, it was five, six hours, and some nights it was, you know, a couple of hours, but every night I would study through the internet. Just explore what robotics is about where to go and how to do it." (James Williams) "So can I get that if I can get this to rise? And then I realized nobody around us is competitive. Like that's not pushing my kids. So then I started sharing, sharing with Morado, sharing with Kellar ISD up in the like… we went up there and I started helping them and then we brought them down and started sharing information with them. And so all of the teams in the area, I just, if they asked, I helped. And then I started volunteering at the events because I realized I had a better knowledge pool and most of the other people in the area did help with Judge advising, helping with roughing, and making calls that I felt like would be called at the regional meet, or would be called at the world meet, and pushing everybody around me. Like I cannot rise by myself at this point, I needed to make this entire area more more competitive, or else I will not stand a chance at the world level." (John Smith)

> took this to be an elective and be near a buddy. And if I give them a specific task, they'll do it. And they'll do quite well, actually, because we got good kids. But if I do not give them a specific task, or if I'm working on something else with somebody else, then they can get distracted quite easily and become a problem. But if I'll give them a specific task, they'll do it. I do not know if they would do that for just everybody. But they do know that I care about them. They'll do what I asked them to" (Steve Brown).

Additional quotes from teacher participant Steve and others that correspond to this portion of the TLMS framework are provided in Table 8.

For the TLMS Domain V, *improving outreach and collaboration with families and community*, the robotics teachers provide detailed descriptions of how valuable the communities are and the unique opportunities that are present for showcasing teacher leadership. Recognizing that external funding is key to supporting the continuation and growth of the robotics programs, several teachers recall the importance of parental involvement and how the presence of families at the robotics competitions makes a big difference in the motivation and participation of their students in these programs.

> I know when the Hispanic side… I had a young lady, her parents were from Mexico. And they thought that she needed to get married, have children. That was their, their goal for her. She joined the robotics team. They did not want that. They hated that. They fought with her about it. She'd come to practice crying because they would tell her that that wasn't right. Girls did not belong in the robotics technology field. And she fought with them. And she… I just keep telling her, it's okay. It'll get better. Just keep going. And then the first year, we won state. And she comes over to me and she was bawling again. And I'm like what's wrong? We just won state you know, she said, "My mom just called me how… how, how happy she was for me and proud of me for what we achieved." And then they were moving back to Mexico. They should not… lady wants to get into an engineering field. So we contacted the University of Mexico to get her in down there. And so we try to help our kids anyway, we can. You know, some of them do not have the easiest life in the world. But this can get them to that… a life that's a little bit better" (Ricardo Lucero).

Table 9 provides additional information from the interview data related to the improving outreach and collaboration with families and community portion of the TLMS rubric.

For the TLMS Domain VI, *advocating for student learning and the profession*, the robotics teachers were often faced with contradicting the traditional stigmas that the STEM field has been known for, including gender and racial biases that impede student involvement and interest levels. One of the teachers discussed:

> …She actually took additional courses her junior year, to be able to be involved more in the robotics program. She went from a student that wasn't writing very well and did not really know how to put sentences and paragraphs together to actually being the lead on our engineering notebook, which at the time was over 300 pages. And she oversaw that. She was linked to the grammatical errors and corrected the boys and, and just made sure that they made their firm deadlines. So because of all of that exposure to higher level thinking and higher level skills, even though they were soft, that really felt… it allowed her to gain confidence. And

TABLE 8 Transcript excerpts for TLMS domain IV.

Domain	Description	Example quotes
Facilitating Improvements in Instruction and Student Learning	TLs reflect to improve student learning and develop a curriculum that addresses issues of equity and diversity	"… She actually took additional courses her junior year, to be able to be involved more in the robotics program. She went from a student that wasn't writing very well and did not really know how to put sentences and paragraphs together to actually being the lead on our engineering notebook, which at the time was over 300 pages. And she oversaw that. She was linked to the grammatical errors and corrected the boys and, and just made sure that they made their firm deadlines. So because of all of that exposure to higher level thinking and higher level skills, even though they were soft, that really felt… it allowed her to gain confidence. And she's still to this day on her Facebook posting. Her education is priority, graduating with the diploma was a priority, helping to inspire others in her demographic of females, Hispanics, it does not matter to her as long as girls have a voice, in her heart, and know that someone believed in them." (Ricardo Lucero) "So yeah, there's a lot of passion. I say, the grit and just… the Panhandle spirit, I guess is what they call it, right? It's just very unique and very diverse and very different. I go to go visit with college recruiters, as I've taken students to different types of colleges, not just in our area, but across the state. And they hand me their business card. They do not have to, they are like, we will take your Panhandle students over an urban area or inner city. Because again… and I said… Why do you…Why do you say that? They're like, your work ethic, your creativity, your character. They did not say old fashioned, but they said your kids…you'll say Yes, ma'am. No, ma'am. I guess just your character. Because it was a foundational thing for our area, just like, as I mentioned, the foundational things for gracious professionalism for FIRST. And so those are just hallmarks of who we are, our fabric, if you will, for our community and for our students. And so it's that hard work in times of adversity. Right?" (Ricardo Lucero) "I think they do. I think they have, they have grown up in a hard society. And I think they know to survive. That they have got to, they got to better themselves. I think that's an offset with all of them, that they are all looking to make themselves better. You know, my dad did construction and I knew I wanted to do something more than construction. You know, the first year, first year teaching, I made more than my dad made. He worked here around three jobs and worked hard. He knows that you want to be better and my kids want better. And they want to go to college. They want a good job. And they see that this is a way to do it." (James Williams) Well, I do my very, very best to find them a job that they will tolerate. Not necessarily that they like or that they are good at but one that they will tolerate. I need you to organize that toolbox. They might tolerate that. They want to be a part of anything else. But they better do what I ask. Every child that I've got that I've ever had will do what I ask or at least try it. The ones that really want to be here, you know, they have got specific jobs and they do everything all the time. But I do have a couple this year that only took this to be an elective and be near a buddy. And if I give them a specific task, they'll do it. And they'll do quite well, actually, because we got good kids. But if I do not give them a specific task, or if I'm working on something else with somebody else, then they can get distracted quite easily and become a problem. But if I'll give them a specific task, they'll do it. I do not know if they would do that for just everybody. But they do know that I care about them. They'll do what I asked them to. (Steve Brown)

> she's still to this day on her Facebook posting. Her education is priority, graduating with the diploma was a priority, helping to inspire others in her demographic of females, Hispanics, it does not matter to her as long as girls have a voice, in her heart, and know that someone believed in them. (James Williams).

Table 10 provides additional participating RRT leaders' example excerpts associated with Domain VI of the TLMS framework.

Within the application of the TLMS framework to rural settings in STEM content areas, Lotter et al. (2020) provided three important additional foci for rural teacher leadership, including (1) the significance of relationships with students, (2) significance of relationships with community members, and (3) the influence of strong resource networks. In our study, each of the four teachers provided clear examples of meaningful connections with students and community members, a difference that supportive resources make for both the ER programs and the depiction of strong teacher leadership development. For example, one of the teachers expressed:

> You've got to be willing to stick around for a few years like that, that commitment and like that personal commitment to the school to the community, and into the students that they can they think you are going to be there, you are a fixture in their mind, it does not take that long for them to enter high school for them to feel like you are a part of the high school (John Smith).

The development and maturation of student relationships have been discussed as highly relevant components of what strengthens both the robotics programs and teachers as leaders within these experiences in the rural setting. Table 11 contains data that correspond to the additional foci for rural teacher leadership development with these ER teacher participants.

Overall, the findings demonstrate how the TLMS applies and expands within the context of competitive robotics programs in rural schools (RQ1). While the TLMS domains provided a useful structure for analyzing leadership practices, the data revealed key expansions to the framework, including the importance of partnerships with industry professionals, the integration of informal learning environments such as competitive robotics teams, and the development of advocacy roles that extend beyond the classroom to families and communities. These expansions highlight how the unique challenges and opportunities in rural contexts, such as limited

TABLE 9 Transcript excerpts for TLMS domain V.

Domain	Description	Example quotes
Improving Outreach and Collaboration with Families and Community	TLs work with families and utilize the expertise in their communities to impact student learning	"And then getting your community support is also part of the FIRST program, is trying to build your connections with your community and have them support you because it's, it's very much a business model, sort of a thing, when you are trying to get out there and engineering… you need to get your sponsors and you need to have all your money in place before you can do your project. So I think that's part of why they want that. And so having that element required in the program was very helpful when I was in Corazon because the kids were out having to talk about the robot all the time." (John Smith) "Very impressive. This town is one of those special communities. They'll give, they'll give, and they'll give. But most of them either work at Valero or have farms where they make pretty good money and they want to keep putting money back into their kid's education." (Steve Brown) "I know when the Hispanic side… I had a young lady, her parents were from Mexico. And they thought that she needed to get married, have children. That was their, their goal for her. She joined the robotics team. They did not want that. They hated that. They fought with her about it. She'd come to practice crying because they would tell her that that wasn't right. Girls did not belong in the robotics technology field. And she fought with them. And she… I just keep telling her, it's okay. It'll get better. Just keep going. And then the first year, we won state. And she comes over to me and she was bawling again. And I'm like what's wrong? We just won state you know, she said, "My mom just called me how… how, how happy she was for me and proud of me for what we achieved." And then they were moving back to Mexico. They should not… lady wants to get into an engineering field. So we contacted the University of Mexico to get her in down there. And so we try to help our kids anyway, we can. You know, some of them do not have the easiest life in the world. But this can get them to that… a life that's a little bit better." (James Williams) "I know Morado, Blauzweig, the whole county, they do not have that. But I know the parents do come together and do everything they can to facilitate with whatever funding they are able to do in the form of a meal fundraiser, a t shirt fundraiser. Those parents do come together because again, they see our kids are really engaged. The behavior is not as, you know, it's been before, or I see it, it's a positive behavior change. And so they do come together in the capacity that they can in their communities to contribute to their students interest. And because of seeing that, again, their level of engagement. And so everyone's just a little… we have a larger, slightly larger pool of companies that we can pull for or go out and ask. But again, our principal here, at Helium Tech also does that, not just for the robotics program, but every program inside of Helium Tech Career Academy. He advocates and tries to get funding and resources outside what the school can provide. So that we can really, not be better than anyone else, but offered the best that the community can offer for its students." (Ricardo Lucero) But if I could change… if I could get some support, what I would really like to see… and this is kind of contradictory to what I've been saying, but it's true, is more parental involvement. My parents support my kids a lot. And they make sure they are here. And they make sure they are, that they show up to go to tournaments. But they do not come watch. Because it's not football. Now, that's my personal soapbox. But if I could get more parents to come and watch their kids, it would be even better. I understand that we traveled to [team where Dr. Brumley is located], and we traveled to Helium. And we traveled to Windy City. And if we are lucky, we travel to Dallas or Austin. And that's difficult for parents with a job to be to show up to. But if I can change one thing, I wish I would have more parental support in that aspect. Making sure they are here though. That's, that's important. And they do that. But only, I wish they got to go… to show up to watch. Out of 21 sets of parents. I've got two sets that show up to watch. (Steve Brown)

TABLE 10 Transcript excerpts for TLMS domain VI.

Domain	Description	Example quotes
Advocating for Student Learning/ Profession	TLs understand policy and advocate for students and teachers to promote student learning	"A lot of those moments here. I wasn't just saying it happened that one time, that's the only time. But yeah, that's what makes it. That's what makes me want to keep coming back. Because I love my kids. And I love it when I can teach one thing. One thing, if you only learn one thing, and you let me know that you learned it, I'm going to be happy. If I teach you a whole bunch, even better, but that is what makes it worthwhile." (Steve Brown) "I would tap kids on the shoulder and say, I want you to join my robotics program when I was in the middle school in Corazon. But over there [Prairieview School], there was enough kids that they would just come because they thought engineering sounded cool. And they would come. And then when I came over here to Blauzweig, the population here is… I do not know about 15%, Hispanic, the rest white, and then maybe one or 2% Black, and that's about what we have got. My teams in Corazon, I also did… I purposefully targeted females and drug them into the program, we were a little over half female. And to me that was important to make that happen. I wanted it balanced. I knew that in my classroom if I had a balanced classroom, gender wise, things were much more successful as a teacher." (John Smith)

TABLE 11 Transcript excerpts for additional rural teacher leader development foci.

Domain	Example quotes
Understanding the significance of relationships with students	"So my relationship with my students does not end when the program ends, I tried to continue… I try to continue the relationship with them beyond because of mentorship, because I still care about them as people and I tell them when you decide to finish your relationship with me, that's okay. But my doors always open for you because, you know, not having that support myself. Just having someone a bit… to listen to maybe get some general advice because I'm not an extra by any means. It's just that I had lived life and had some hard lessons myself. And just going through the process of Life, I feel that that's what said… I may not know the answer. But let us look at this resource. So you may want to talk to this type of person or let me help see what I can find out for them. But just know that they are still involved in the STEM community and being productive. And Mateo was also another one that was one of our panelists for Helium Tech robotics program so that our students could know that the relationship continues to be on after high school, into the professional, into college. So they talked about their college background, some of their struggles, what they would wish they would have known if someone had told them starting out in a STEM career related field of study, and then how to navigate early on because very early on in the career, how to navigate through what's, you know, how to appropriately prepare for a professional interview. The types of questions that they could ask you, how to actually answer those questions that will get you maybe, get a second interview, or a follow up interview to another interview." (Ricardo Lucero) "You've got to be willing to stick around for a few years like that, that commitment and like that personal commitment to the school to the community, and into the students that they can they think you are going to be there, you are a fixture in their mind, it does not take that long for them to enter high school for them to feel like you are a part of the high school." (John Smith) "Do you need to bring your siblings? Bring them. We'll find something for them to do. We'll leave them, let them drive the robot to get that excitement in them. You know, so. So for me that, you know, some people do not like that. To me, I understand that our students have to work support the family. So we make you know, who's working this week? When do we need to have practice? Let us work around your practice. What time do you get out of practice? What time you get out work? Let us start practice after that. So we do what, whatever it takes is the bottom line. It's, it's because… I understand, you know, growing up myself, it took my dad working three jobs and my mom working one job to support the whole family so that we could do different things. And it's no different except for it takes more money now to raise kids than you could back then. And so these kids have to you know, it's just a way of life. They've got to work to support to be able to buy their stuff. Because sometimes a family cannot buy new pants, new clothing, cell phone… gotta have that new cell phone. So they work for that. So we work around." (James Williams)
Understanding the significance of relationships with community members	"Some of the kids had those conflicts. Work came up a few times. Most of the time, they could talk to whoever they were working with and explain to them that they are there on the robotics team, we have got to meet we have got to practice it because it does not. We did not do it all the time. Usually we would put in after-hours work close to an event because we could see that a deadline was approaching and so it was us burning the midnight oil. And so whether, it's whether it was siblings that they may, that happen, if the kids expressed to their parents or their employers, at least in Corazon, that they wanted to come and do this thing, the community made it happen. Again, kind of that community support, family support, they may not have shown up to watch, but they have made it possible for their kids to go and do these things." (John Smith) And then getting your community support is also part of the FIRST program, is trying to build your connections with your community and have them support you because it's, it's very much a business model, sort of a thing, when you are trying to get out there and engineering… you need to get your sponsors and you need to have all your money in place before you can do your project. So I think that's part of why they want that. And so having that element required in the program was very helpful when I was in Corazon because the kids were out having to talk about the robot all the time. (John Smith) "Oh, different. I have a mother and a grandmother of a, one of my children who loves to volunteer for stuff like that. And so they were my… two of them were my, two of my referees. And then I had to rely on Windy City, [other large University], for my head ref. And for a few other referees. At a local tournament, you do not have to have judges for interviews, you do not have notebooks, which is what you are probably familiar with. We do not have to have those at a local tournament. And I had two other volunteers that wanted to be scorekeepers. And I had to rely on [other large University] to report to provide me with the rest. And they just reached out to the other teams and said, Hey, we need a scorekeeper. You know, and somebody volunteered. Hey, we needed another judge, and somebody volunteered. And then I had another mother who wanted to be involved. And she was my queuer and her daughter, who were not in robotics at that particular time, but she joined next year. They were my queuers, and I just sent out a lot of emails, mass email to everybody on staff. Said, Hey, I need this. And I got volunteers" (Steve Brown)

(Continued)

TABLE 11 (Continued)

Domain	Example quotes
Understanding the importance of strong resources networks that can provide both financial and affective supports	"So the school district provides a good portion of it, because we do receive Perkins money, and we receive money for students that we, that are termed Title one. And so, but they are not directly to the program, there's a portion of those funds that can go to it, we do have to fundraise. Because like travel is not included. What's another thing that's not been included, fuel is not included. Certain supplies are not included. And so therefore we do have to fundraise it. Again, at the very beginning of the season, we can either have a fundraiser or this year, we actually tasked the students with, you have to find at least one sponsor of $100. And so they did that. And actually the sponsors, which were mostly their parents or their companies that their parents work at, actually made substantial contributions. And so we were able to build a very nice pillow, or cushion if you want to call it, of funds." (Ricardo Lucero) "Whereas he's got donors that just write him checks, we do not have that out here. We have some, you know, I get a little bit from the windmill. I get $2,000 from the windmill [Wind farm]. Every year, they have been good for us. There's a construction company that in [largest municipality in the region] has given me donations, because I coached the owners of the company. So they give back to me. So we have it that way. Those big cities, a lot of those kids even in [largest municipality in the region], you know, the robotics team in [largest municipality in the region], at Verde Tech. They were told, each kid, to go out and get $2,000 for a donation, to sponsor, and they were having kids bring back $8,000, $9,000. We do not have that here. We do not have that kind of money." (James Williams) "And likewise, over there [Corazon] to have a lot of the other staff and the other students, you know, give you a good job, high five, when you came back from doing something. When I was seeking funds in Corazon from the community, I would go to the bank, I would go to the grocery store, and we would ask them to sponsor us. We would not, this was just me, but we would not fundraise like normal, we would just go ask for money for the stuff that we needed to do from the organizations and businesses around town. And by and large, we would just list out our budget and say, 'This is what we have done so far. And this is what we need to make things happen for the rest of the way." (John Smith) "But I keep reaching out, I keep going to clinics, I keep studying it, you know, you have got to put in the time, even as, even as an instructor, you have got to put in the time. This year, we outreached with a team out of Henderson, Texas, which is Far East, and we did a video clinic with them, we sent them parts, because they could not get parts, we set them parts." (James Williams)

resources and the need for external mentorship, shape the enactment of teacher leadership in STEM fields beyond traditional mathematics and science settings.

Additionally, the study identifies core experiences that shape RRTI development (RQ2). These include building collaborative networks with peers and external experts, advocating for equity and access to STEM learning for diverse student populations, and taking the initiative to engage families and communities in support of robotics programs. Teachers' experiences with problem-solving in resource-constrained environments, navigating cultural expectations, and mentoring students in both formal and informal settings emerged as central to their leadership growth. Together, these findings illustrate how RRTI development is both shaped by and contributes to the expansion of the rural teacher leadership framework within the context of integrated STEM education through competitive robotics.

Discussion

While elements of the framework could be linked to each individual teacher's experiences, the relationships between several framework components that are naturally inherent in the rural school context paint a picture of the development of the RRT leader, exemplified through their shared experience. For example, teacher participants in our study stated that they encouraged other RRTs to facilitate their own programs and held conferences to share their knowledge of ER. TLMS Domains I and III and Lotter et al.'s (2020) additional criteria within the rural context of having the Influence of Strong Resource Networks all convey the idea that teacher leaders "communicate their expertise and leadership efforts to broader communities" (Criswell et al., 2018, p. 1267). Although, in this context, that broader community may consist of other RRTs separated by the rural geography, this building of community within themselves is needed and necessary, as rural STEM teachers are often the only, or one of a few, that teach within a content area (Marietta and Marietta, 2020; Rivera et al., 2023; Vestal et al., 2025). In the case of RRTs, these educators must rely on outside resources for professional learning and continuous improvement, as participants in this study were the only robotics teachers at their school and, thus, had to develop their own collaborative community to the best of their ability. By seeking assistance and banding together with other RRTs or seeking out the expertise of those in the robotics, engineering, or computer science fields outside of PreK-12 education, these RRTs were able to develop the informal collaborations required to continuously improve in their robotics content area. These improvised professional learning communities then allowed the RRTs to promote their robotics educational practice, hone their knowledge and skills for facilitating ER, and strengthen their resource network.

These ideas also extend to TLMS Domain II. It is true that the RRTs in this study took it upon themselves to research robotics programs, seek out mentors to supply information to fill in gaps in their knowledge, and, in some cases, find the resources to teach themselves the content. However, within the description of this TLMS, Lotter et al. (2020) detailed that this portion of the framework requires "the responsibility to communicate learnings to a larger audience" (p. 32) through

presentations at conferences or sharing through articles. Now, while the RRTs were not necessarily using their research in the sense of producing a scholarly product, sharing their knowledge was more applicable and directly impacted what would occur in the classroom through the dissemination of knowledge within their extended, geographically expanse, and collaborative community. The RRTs in this study understood the importance of new knowledge and systematic inquiry that could advance their students' learning and felt a responsibility to communicate that knowledge with their broad RRT community. However, assessing information and conducting research in this way comes with caveats. For starters, engaging in assessment and study takes significant time, as one must stay cognizant that the information is current, reliable, and applicable. Moreover, teachers looking to supplement their curriculum or knowledge base must ensure they are using best or standards-based practices.

While ER use in secondary schools is still a relatively new concept that is making progress toward more widespread adoption at the secondary level and in more formal settings (Benitti, 2012), the need to seek outside information and resources for improving practice and student learning may not be specific to robotics teachers in the rural context, but not having collaborators, networks, or easily accessible professional learning are factors that have historically pervaded teachers, specifically STEM teachers, in rural schools (Marietta and Marietta, 2020; Rivera et al., 2023; Vestal et al., 2025). Thus, in a way, these teachers already inherently understood the need to seek out this assistance and information and were well-versed in developing their robotics teaching practice through these methods. It is possible that the rural context, through the ways in which teachers form provisional communities, gather, research, and assess information, and seek professional development in this space, more readily facilitated the development of these RRTs as leaders.

In a similar vein, the relatively small numbers of students in these rural schools allowed for the development of significant relationships, identified by Lotter et al. (2020) as an added point in rural teacher leadership development, and contributed to the alignment between the teacher participant's experiences and TLMS Domains IV and VII. As rural schools often do not provide access to as diverse of an array of STEM content subjects and courses as their urban counterparts (Saw and Agger, 2021), the RRTs in this study had a passion for teaching STEM content and advocated for their students by providing the opportunity to engage in ER as part of their STEM curriculum offerings. In analyzing their experiences, it was clear that each teacher had a passion for both robotics and their students and saw how robotics offered a chance to make a difference in the lives of their rural students by giving them access to STEM content previously not available. In addition, limited enrollments in rural schools may hinder the provision of course offerings (Gagnon and Mattingly, 2016), and the teachers in this study utilized their built connections with students to recruit to their robotics programs to ensure that ER remained a mainstay of curricular offerings. Teacher participants communicated that students' interest in robotics was initially due to their relationship with them as their teacher. However, it eventually evolved into engagement, curiosity, and enjoyment with STEM knowledge and skills developed through ER participation. These teachers also used their deep understanding of their students to identify those with skills and knowledge that could be nurtured by participation in ER.

Along with developing significant relationships with students, teacher leaders in rural areas must also develop significant relationships with the community (Lotter et al., 2020), and this idea extends to the TLMS Domain VI. For the RRTs, support from communities and families came in many forms and was, in some ways, bidirectional. Funding is one such form of community support that was a necessary component for these RRTs and their program, as technology and tools to facilitate ER can be expensive, and limited budgets and funding are a common problem present in rural schools (National Academies of Sciences, Engineering, and Medicine, 2025). Therefore, these teachers took it upon themselves to apply for grant support and reach out to industry partners and families for funding, and in doing so, informed their community of the benefits of ER participation and the learning that could result. This then afforded the community and families access to the STEM content being learned as a result of ER participation, awareness of STEM opportunities and careers, and the ways this impacts and occurs in the rural area. It is also interesting to note that in each rural robotics teacher's case, the administration was highly supportive and committed to their respective ER program, with all schools recognizing the program's need and benefit for their rural students. This is an important result to note, as administrator support is a key element in the development of teacher leaders (Lotter et al., 2020). In fact, one RRT in this study served as both the robotics teacher and principal, which is not uncommon in rural schools where administrators and teachers often serve in multiple roles and areas as needed (Lotter et al., 2020; Marietta and Marietta, 2020). However, this conveys a commitment and the desire of the rural schools in this study to offer quality STEM experiences to their rural students through any means available.

An interesting outcome from our analysis of RRTs' experiences and their development as leaders occurred within the TLMS Domain I. In that regard, the RRTs stated that while many ER options exist, the choice of robotics program for their school was based on values that directly aligned with the values of the rural community. For example, one teacher leader related the robotics program's core values, such as "gracious professionalism" and "co-opertition," offering assistance to those with whom you are competing in an effort to make all involved better, coincided with behavior in rodeo competitions. Another mentioned outreach and giving back through volunteer work in the community and with other students to garner interest in robotics. While some consider integrated STEM content to be full of humanistic values oriented toward citizenship (Ortiz-Revilla et al., 2020), the fact that the RRTs in this study mentioned values as an important measure in determining how STEM teaching and learning is presented is an interesting result. This finding conveys the worth placed by these RRT leaders on moral principles in STEM and the role that place, and the values of that place, may have in the delivery of that STEM content.

While our results present important implications for the value of ER programs and teacher leadership within STEM, we should acknowledge the limitations of our study. The first is that our data is based on one interview with rural teachers. It should be mentioned that one of our investigators served as a volunteer for the ER competitions over the course of a year and, through this engagement, developed relationships and rapport with project participants. Although these relationships were strengthened through this prolonged interaction with participating teachers, the geography of the rural landscape also played a role in conducting only one interview, as travel to the schools was a minimum of 45 miles one way.

Another limitation of our study is the relatively small sample size of RRTs. However, small populations in rural areas are a reality that

contributes to the complexity and challenge of conducting rural education research (Bovaird and Bash, 2016). Yet, this limited size is largely due to the recent emergence of competitive ER program offerings in rural schools. As more rural schools can incorporate this form of STEM learning to provide students with access to STEM content not previously afforded in their rural place, the pool of RRTs will increase. However, information from participating teachers about their experiences further demonstrates the need to hear from unique STEM teacher leaders operating in diverse contexts, including rural areas. A recommendation for further study to strengthen the research base would be to combine interview data with classroom observations or student performance data based on ER instruction. The description of the programs, learning for both teachers and students, curriculum, and the instructional methods used to integrate STEM concepts, and the outcomes of these competitive programs in ER bring to light the ideas inherent in the formation of RRTI (Criswell et al., 2018). The developing identity is molded not only by teacher components but also by student involvement, the school system, community support, and the multifaceted robotics program elements that all play essential roles.

Conclusion

The results of our study provide several important contributions to both the STEM and rural education fields, as well as provide support for the strength of the rural teacher leadership framework. Although the small sample size is limiting, this study contributes to a sparse research base that explores teacher leadership development in rural spaces with teachers who facilitate ER in formal and informal settings. In terms of developing teacher leaders poised to facilitate formal and informal STEM learning through ER, the rural context was a prime setting. Given that STEM teachers in rural contexts have unique concerns regarding STEM teaching and learning, these RRTs responded to challenges and issues in distinctive ways. The RRTs saw a need and desire to diversify their STEM offerings through ER and advocate for their students' learning through ER, both formally in the classroom and informally through extracurricular competitions. These RRTs accomplished this by fostering a collaborative culture, using research and professional learning to serve needs and facilitate improvements, and were creative in doing so through their relationships with each other, their students, and the community. Thus, in these ways, these RRTs developed as STEM teacher leaders.

Implications from this research extend to ways that educational stakeholders may understand ER teaching and learning as it applies to the rural setting. This research also offers suggestions for the field regarding content-specific teacher leadership development and offerings for robotics knowledge and skills development in K-12 robotics education. Our findings explicitly connect Lotter et al.'s (2020) teacher leadership framework to the lived experiences of rural teacher leaders, highlighting the important role that ER plays in rural contexts. Second, the thematic analysis revealed the value that the rural context provided when considering the development of robotics teacher leaders. Third, this study demonstrates a direct application of this framework to distinct rural schools and communities. Finally, the findings of this qualitative approach contribute to the existing limited research focusing on the rural southwest, recognizing that most current studies using this framework have been in the rural southeast.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the West Texas A&M University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AM: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AR: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. MI: Conceptualization, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. AS: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. BQ: Formal analysis, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing. BC: Formal analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

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

Generative AI statement

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

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