frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 17 June 2025
DOI 10.3389/feduc.2025.1578370

OPEN ACCESS

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RECEIVED 17 February 2025
ACCEPTED 15 May 2025
PUBLISHED 17 June 2025

CITATION
Rivera S, Kavanagh K, DeWaters J, Ramsdell M, Burkhalter L, Johns L, Taylor N, Smith M and Beldock L (2025) Secondary school-university partnerships foster STEMM interest and self-agency in rural students. *Front. Educ.* 10:1578370. doi: 10.3389/feduc.2025.1578370

Secondary school-university partnerships foster STEMM interest and self-agency in rural students

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Introduction: Rural STEMM education faces significant challenges, including limited access to high-quality STEMM experiences and resources. University-K12 partnerships can address these challenges by providing opportunities for students and teachers to engage in authentic STEMM activities, build relationships with STEMM professionals, develop critical thinking and problem-solving skills, and grow professionally. This paper explores the unique assets and challenges of such partnerships in a rural, geographically isolated region of Northeastern United States.

Methods: We examine several successful STEMM programs directed by a small university through a qualitative exploratory approach. These programs include a neuroscience program, place-based environmental outreach, a student space program, and a science and technology entry program.

Results and discussion: Through an analysis of reflections from teacher partners and program leaders, prominent themes emerge and critical factors are identified that contribute to success. A key finding is that teachers naturally emerge as cultural navigators who provide vital support and guidance to all stakeholders in a rural STEM network resulting in a range of positive outcomes.

KEYWORDS

rural, teacher, university, school, partnership

1 Introduction

Science, Technology, Engineering, Math, and Medicine (STEMM) programing between K12 school districts and universities can provide transformative experiences for students (Bryan and Guzey, 2020). These partnerships are critical for bringing relevance to classroom curricula, strengthening problem-solving skills, equipping students to make informed decisions, and paving pathways to STEMM careers (Lent et al., 2000; Maltese and Tai, 2011; Wang, 2013). This is especially true in rural areas, where significant barriers to quality STEMM education exist (Burrows et al., 2012). While different perspectives give rise to a range of definitions for *rurality*, rural areas are often considered secondary to urban

centers in our metrocentric society. Instead, we focus on highlighting the unique assets of a rural community while simultaneously acknowledging the challenges that exist in rural settings.

Among the many challenges that hinder successful outreach in rural areas, such as lack of resources and geographical isolation, is the disconnect between students' identity and the college programing. Students might not participate in programs because they don't feel a sense of belonging with the professors, students, or professionals who deliver the experiences (Simpson and Bouhafa, 2020). Cultural and racial dynamics and socioeconomic struggles prevalent within rural communities exacerbate these feelings (Burrows et al., 2012) Similarly, students may lack support from parents who don't recognize the value of these opportunities (Burrows et al., 2012). Another challenge relates to a general lack of awareness and sensitivity among many college professionals regarding the specific needs of the rural student community. For these reasons, including teachers at every step is critical to the success of the programs. Teachers' deep understanding of the culture in high-need schools is essential to bridging the gap between the curriculum and content prepared by university faculty and implementing programing for K12 student learners.

In this paper, we share programs developed through partnerships with a small, private STEMM-focused research university, Clarkson University (CU), and multiple school districts across the rural, geographically isolated region of Northeastern United States. We investigate four successful programs: a neuroscience program, place-based environmental outreach, a student space program, and a science and technology entry program. Some of these programs were developed over 20 academic years, highlighting the university's strong relationships with the surrounding rural schools. These partnerships are operated through the university's Institute for STEM Education, which facilitates programing that reaches over a thousand K12 students and hundreds of teachers annually.

Our study explores program components that contribute to successful university partnerships in rural regions that center on STEMM, using observations by program leaders as well as three veteran teachers who are long-time partners. This work builds on previous studies that viewed university partnerships through the lens of only the program leaders (DeWaters et al., 2025; Kavanagh et al., 2022). Through a qualitative approach, we examine teachers' narratives to identify factors influencing their decision to partner with universities, as well as the impacts these programs have had on them and their students. The following research questions guide the study:

1. What are the unique assets and challenges among our higher education-K12 rural partnerships?
2. What are the lessons learned from engaging in this work?

Through the teachers' narratives and perspectives of the program leaders, we identify key strategies that lead to impactful collaborations among all stakeholders. By acknowledging and addressing the challenges described above—student identity gaps, disparities in institutional resources, and the effects of generational poverty—partnerships can become more effective.

2 Background/literature review

2.1 Rurality

The National Center for Education Statistics (NCES) relies on the U.S. Census Bureau's definition of rural which is a population density of fewer than 5,000 people; NCES further distinguishes rural territories into fringe, distant, or remote areas (NCES, Retrieved April 14, 2025). However, differences in how "rural" is defined often arise from varying perspectives on what constitutes a rural area. These perspectives include factors such as distance from an urban center, degree of "connectedness" (typically measured by commuting patterns), population density, population size, or proximity to an urban area through shared political borders (e.g., counties). Rural areas are often considered secondary to urban centers in our metrocentric society. We support the idea of rurality as a cultural construct (Kline and Walker-Gibbs, 2015; Reagan et al., 2019) and counter the narrative that oversimplifies the complexities of rural areas (Lichter and Brown, 2011). This view appreciates rural communities' unique assets while acknowledging the challenges of rurality.

In rural areas, schools play a unique role as community anchors (Schafft, 2016). A qualitative study by Tran et al. (2020) highlighted that teachers in rural schools often emphasize the close connections between schools, communities, and families. This tight-knit community support is more prevalent for rural students than their non-rural peers (Byun et al., 2012). While parents of prospective first-generation college students may have limited knowledge about college pathways, teachers, school counselors, and college advisors can provide crucial guidance and resources throughout the college-going process (Morton et al., 2018). Teachers' expectations have been shown to positively influence rural students' educational aspirations and achievements (Means, 2019). However, persisting and fully engaging in STEMM is challenging for students in rural schools, where there are few opportunities to engage in STEMM both inside and outside the classroom (Saw and Agger, 2021). Historically, students in rural areas tend to face a multitude of exceptional challenges, such as economic challenges that limit educational opportunities and future career pathways, geographic isolation, and lack of access to high-quality STEMM programing and advanced STEMM coursework (Brenner, 2016). In addition to the limited visibility rural schools face due to their geographic location, institutional barriers also exist, such as limited financial incentives to recruit STEMM teachers (Silva-Peña et al., 2020), remoteness (Boynton and Hossain, 2010), and inadequate facilities (Kelly, 2016). Ultimately, denying quality STEMM education opportunities to all students is short-sighted for a society aiming to strengthen and reclaim its economic and intellectual position among other developed nations (Harris and Hodges, 2018) and unjustly ignoring rural populations. Research ideas and findings that focus on rural populations or settings often carry broader implications applicable to both rural and non-rural contexts (Weiss et al., 2023). Balancing uniqueness with universality is a core

challenge but holds great promise for advancing knowledge and practices in rural STEMM education.

2.2 School-university partnerships

One way to overcome these obstacles for rural schools is to establish solid partnerships with universities. However, building successful partnerships comes with challenges for all stakeholders. Students may be reluctant to join programs because they don't identify or feel a sense of belonging with the college professors, students, or professionals delivering the content or leading the experience. Many students may not see themselves represented in these groups, making them doubt whether they truly belong in these academic spaces (Gray et al., 2018). This identity gap is further amplified by a lack of similar cultural, racial, or socioeconomic background, which can hinder students' willingness to participate fully (Stebleton et al., 2020). Parents of K12 students may struggle to adequately support their children because they lack familiarity with higher education or the professional landscape (Peterson et al., 2015). Without first-hand experience, parents may feel disconnected from their children's academic journey, resulting in the inability to provide the emotional and logistical support necessary for success. Simultaneously, the college team may not have an adequate background or understanding of the unique challenges students and school districts face due to the lack of resources and, frequently, generational poverty. Due to this lack of awareness or understanding on the institutional side, even well-intentioned college staff may struggle to connect with students or to design programs that effectively address the students' needs (Allan et al., 2016).

Partnership models are increasingly replacing traditional one-time summer courses and workshops as key strategies for enhancing STEMM education in the United States. However, there is limited documentation on how these collaborations between schools and universities are initiated and sustained (Tomanek, 2005). Strengthening public science literacy and sustaining a diverse and capable science workforce requires efforts across both formal and informal K12 education. Numerous organizations—including professional societies, universities, government and industrial labs, and informal science institutions such as museums and planetariums—are dedicated to supporting schools and engaging the public in science. Funders and taxpayers increasingly call upon scientists to participate in these efforts (Dolan et al., 2004). Significant collaborations have emerged over the past several decades between STEMM and STEMM Education experts at universities, informal STEMM education institutions, and the preK12 education sector. One of the models, a "scientist in the classroom," aims to bring the expertise and enthusiasm of professional scientists into schools to spark interest in science and inspire consideration of STEMM careers (Tomanek, 2005; Ufnar and Shepherd, 2018). Other longer-term programs are usually supported by universities, professional organizations, or community groups, with internal or external funding. These partnerships have developed innovative and impactful strategies to strengthen teachers' STEMM knowledge and teaching confidence, improve student achievement in STEMM subjects, and foster greater enthusiasm for STEMM while encouraging interest in STEMM careers (Tomanek, 2005).

3 Materials and methods

This study employed a single-embedded case study design (Yin, 2014), with the university as a single case and four K12-University partnership programs as the embedded mini-cases. We explored these partnerships through the lens of the K12 teacher, examining the teachers' narratives through a grounded theory approach which, according to Charmaz (2006), allowed us to continuously "evaluate the fit between [our] initial research interests and [our] emerging data" (p. 17), ultimately identifying underlying relationships among the themes that emerged. This qualitative research approach enabled a deep understanding of individual perspectives, and provided comprehensive insights into the research questions. Three representative teachers participating in the four outreach programs conducted in partnership with local K12 school districts provided written responses to a set of guiding questions. The following sections describe the context of the study, the teachers, and the data collection and analysis.

3.1 Context

CU is a small, private STEMM focused university made up of the three Schools of Engineering and Applied Science, Health and Life Sciences, and Business, as well as a suite of signature programs that enrich the student experience. CU is located in a geographically isolated region in Rural County (RC) (pseudonym) and is characterized by vast stretches of rural areas with limited access to major urban centers. Based on NCES, CU is considered to be in a remote rural area. According to census data, RC has the second highest poverty rate in [state] with 19% of the population in poverty. The median household income is roughly $62K compared to the state average of $85K (U.S. Department of Education, National Center for Education Statistics (NCES) 2025), with 51.4% of students qualifying for free/reduced lunches. These disparities are exacerbated by the county's limited employment opportunities and access to essential services such as healthcare and education. Only 24.6% of the RC residents have a bachelor's degree or higher compared to 40.6% of [state] residents (U.S. Department of Education, National Center for Education Statistics (NCES) 2025). Consequently, many students come from families that have not been to college, and likely lack the role models and encouragement so vital for pursuing a science-related major in college.

RC school districts also face significant challenges due to limited resources. Many districts have few specialized staff resulting in fewer opportunities for students to engage in emerging STEMM experiences that would ultimately spark interest in STEMM careers or college pathways. These challenges create additional barriers to the pursuit of STEMM professions as students.

The CU Institute for STEMM Education (the Institute), established in 2016, is now the hub for K12 outreach and STEMM teaching support. CU professors participate as faculty or as affiliates in the Institute. Two fellowship-supported graduate students support the Institute's outreach initiatives. We involve undergraduate students who assist with programing, volunteer at events, work summer camps, and mentor high school students. CU provides teachers professional development grounded in

TABLE 1 Program descriptions.

Program name	Program highlights	Program details
CU Discovery space (student spaceflight experiments program)—SSEP	• After school program • Campus visits • Student and faculty mentors • Experiment sent to ISS • Trip to Cape Canaveral	• 150 students annually • 5 Schools • Grades 6-12 • 2 years
Building Rural Aspirations in Neuroscience with Science, Technology, Engineering, and Math—BRAIN-STEM	• Summer camp • Monthly campus visits • After School program • Student and faculty mentors • Interactions with healthcare professionals • Research projects	• 42 students annually • 5 Schools • Grades 9-12 • 1.5 years of a 5 year grant
CU STEP (Integrated Math and Physics for Entry to Undergraduate STEM)—IMPETUS	• After School program w/Summer camp • Monthly campus visits • Student and faculty mentors • STEMM challenges • Field trips • Conference presentations	• 260 students annually • 11 schools • Grades 7-12 • 18 years
Food-to-energy	• In School and after school program • Student and faculty mentors • Community connection • Environmental impact challenges	• 667 students annually • 1 school • Grades 5-12 • 7 years

educational research (Lozo et al., 2011). Our high-impact STEMM programs and infrastructure have provided support for K12 STEMM education in [Northeast] districts for over 25 years (Powers and DeWaters, 2004; Turner et al., 2007; Powers et al., 2008; Fowler and Turner, 2010; Rivera et al., 2019; Wick et al., 2011). The Institute recently directed a National Science Foundation (NSF) Noyce grant, which provided scholarships and training to develop high achieving STEMM college students into STEMM teachers who then go on to work in high-need school districts. In 2021, the Institute's faculty partnered with 14 other universities in an additional NSF-funded project to study rurality and STEMM teacher preparation to investigate how teacher preparatory programs prepare students to work in rural areas, and identify important factors for retaining STEMM teachers in rural school districts.

Four successful programs are the focus of this research. These programs are operated in partnership with one or more school districts in the communities surrounding CU, all of which are considered to be remote rural areas according to NCES. Each program is described in detail below, with highlights provided in **Table 1**.

3.1.1 Food-to-energy

Since 2018, faculty and students have partnered with a local K12 school district to engage middle and high school students in project-based, place-based learning surrounding a food waste separation program in their school cafeteria (DeWaters and Grimberg, 2021, 2022). The program has received foundation grants from industrial sources and, more recently, a federal grant from the United States Department of Agriculture (USDA). Middle and high school students deposit their food scraps into bins that CU students transport to a local learning farm, where the organics are treated in a small anaerobic digester used for education and research purposes by CU faculty. The resulting products are biogas, a renewable energy resource that can replace natural gas and nutrient-rich fertilizer. The strength of this partnership relies on the dedication of school staff, most importantly "Morgan", a special education teacher and advisor to the Middle School Green Team. In addition to managing the cafeteria food waste program, Morgan engages roughly 100 middle school students in opportunities that connect them with CU students and help empower them to take action in their school and community. The students regularly divert 300-400 kg of food waste each week from their school cafeteria's waste stream. They participate in learning activities that were developed by CU students, who guide students to explore the food system and learn about problems related to food waste, and they see first-hand how they are helping to solve some of those problems with their own actions. In the first 4 years of the project, approximately 16 metric tons of food waste was treated resulting in approximately 4,500 cubic meters of biogas, with an energy content of approximately 30,000 kWh (enough to power an average home). Results from program surveys administered before and after their participation show significant improvement in students' understanding of energy, resource recovery, waste systems, and the connections between food waste disposal and greenhouse gas emissions. They also report a heightened awareness of their own waste habits, and more discussions with their families about proper food waste management.

3.1.2 CU discovery space

In 2022 and 2023, CU received donor support to participate in the Student Spaceflight Experiments Program (SSEP), a national competition for students to design experiments that will be conducted on the International Space Station (ISS). SSEP's purpose is to compare experimental outcomes conducted in microgravity with those conducted on Earth. A total of 75 teams with over 300 middle and high school students participated over the 2 years. CU supported teachers and students by providing Zoom sessions about microgravity and hosting two on-campus workshops so that teams could brainstorm and refine plans with faculty experts and CU student mentors. CU students and faculty visited schools and held on-line sessions over the span of 2 months to assist teams as they embarked on writing a formal research proposal for submission. Each year, following several rounds of judging, one team's experiment was selected and sent to the ISS. The winning teams (both from the same school) used CU lab space and equipment. The orchestration and organization required to carry out the experiments was significant. Teams were invited to watch the rocket carrying their experiment launch and tour the Kennedy Space Center. We describe their experience in more detail below.

3.1.3 CU STEP

CU's STEP program is a large-scale STEMM outreach program serving roughly 260 7–12th grade students annually across 11

school districts, who are eligible through free/reduced lunch. CU-STEP has been funded by the [State] Education Department for 19 years. Central to the CU-STEP curriculum are project-based and inquiry-based learning principles that engage students in active learning through collaborations to solve real-world problems (e.g., Kokotsaki et al., 2016). Student activities include conducting original research projects for statewide competition, competing in a range of STEMM competitions (engineering, game-design, and science/math problem solving), and interacting with college mentors and licensed STEMM professionals. The program's mentoring component pairs near-peer college students with participants so that they can discuss selecting and applying to college as well as career options (Rivera et al., 2019).

Campus visits play a crucial role in combating the isolation often felt in our region. These visits offer valuable networking opportunities for teachers, allowing them to connect with peers in their fields and share insights. The year-long program culminates in a weeklong summer day camp focused on roller coaster engineering and motivated by solving a real-world problem (Fowler and Turner, 2010; Wick et al., 2011). Parents and school leaders are invited to attend the showcase to celebrate the students' achievements.

Key to the success of CU-STEP is a teacher coach in each of the schools who is responsible for recruiting students, leading them through the activities, collaborating on new initiatives, and helping us assess program strengths and weaknesses. For example, of the 11 partnering school districts in CU-STEP, we have three teacher coaches who have been with us for 10 years, one for 14 years, one for 15 years, two for 17 years, and one for all 19 years that we have been running the program. Their input has been invaluable in evolving and adapting to the changing needs of students over the last 19 years.

3.1.4 BRAIN-STEM

In 2023 CU was awarded a $1.25M Science Education Partnership Award through the National Institute of General Medical Sciences (NIGMS) of the National Institutes of Health (NIH). The goal of this program, Building Rural Aspirations In Neuroscience with Science, Technology, Engineering, and Mathematics (BRAIN-STEM), is to increase rural student interest in pursuing a career in the health care professions. Based on the long-time success of CU-STEP, the program is structured with weekly after school meetings, monthly campus visits, and a summer camp. The current curriculum centers on the neuroscience of addiction and follows a character, Mike, through his treatment plan, with a focus on how the brain responds to drugs. The academic program culminates in a Clinical Simulation Experience where students design a research proposal based on their own interests and take-aways from the curriculum. This program is in its first full year at the time this paper is written, having hosted one summer camp and kicked-off the after school sessions. There are 42 high school students enrolled from five school districts. Students must apply to the program and acceptance is based on interest in the health sciences and aptitude in STEMM courses.

3.2 Participants

Teacher-authors were selected from among a total of 20 K12 teachers involved most recently in the four highlighted programs. These particular teachers represent three different school districts, and serve as "telling" examples because of their lengthy experience in partnering with the CU on multiple programs. According to Mitchell (1984), "telling" cases are those where unique circumstances reveal previously obscure theoretical relationships (p. 239). The teacher-participants are described more fully below; pseudonyms have been assigned to retain anonymity of the particular survey responses.

3.2.1 Morgan

Morgan is a Caucasian female who comes from a suburban upbringing. She teaches at a relatively large, rural K12 school district that serves 1,062 students, approximately 90% white with a fairly even gender distribution with one non-binary student. The student: teacher ratio is 12:1, the attendance rate is 93%, and 85% of the students successfully graduate. The district is in a community that hosts two universities, with 30.7% of students qualifying for free/reduced lunch – fairly low relative to the county overall. Morgan has 28 years of teaching experience and is specialized in Special Education PK12. She primarily works with students in grades 4-8 doing specialized, small group and individualized reading remediation. Morgan has worked with CU for the past 6 years as the primary partner for the Food-to-Energy project, and also participated in SSEP. She is the long-time advisor for the Middle School Green Team, and has helped facilitate several other enrichment programs, often in collaboration with CU partners, such as partnering organizations in the area of agriculture.

3.2.2 Ryan

Like Morgan, Ryan is a Caucasian female, but unlike Morgan she was brought up in a rural environment. She teaches at a small rural K12 school district that serves 313 students, 95% white, with a 54:46 female: male gender ratio and one non-binary student. The attendance rate is similar to Morgan's district at 93%, but the student: teacher ratio and graduation rate are both slightly lower at 9:1 and 79%, respectively. Likewise, this community is more economically challenged, with 55.5% of the students qualifying for free/reduced lunch, which is higher than the county average. Ryan is a secondary science educator who specializes in general science 7-12, biology 7-12, a middle school extension in Biology 5-6. She has approximately 28 years of experience teaching science in grades 6-8, biology in grades 9-10, chemistry in grades 11-12, and environmental, forensic, and earth sciences in grades 10-12. She has been a partner teacher for 19 years in the CU-STEP program, and also participated in SSEP. Ryan is also engaged in NASA HUNCH, and has served a range of professional service roles including various union positions and committees as well as mentoring new teachers.

3.2.3 Delaney

Like Ryan, Delaney is a Caucasian female with a rural upbringing. She teaches in the largest of the three school districts, serving 1,398 students, 94% white with a fairly even gender distribution. Like the other two districts, the attendance rate is high at 92%, and the student: teacher ratio and graduation rate fall somewhere in between at 11:1 and 82%, respectively. Unlike the other two communities, the area served by Delaney's school district is designated as a "city," implying a slightly higher population

TABLE 2 Survey questions.

1. How do you define rural?
2. As a teacher, what are the challenges/barriers of working with a university? What are the benefits of working with a university?
3. Do your students become more interested in STEMM after university-school experiences? Do students feel like they are part of the STEMM community?
4. What is your role in facilitating the relationship between the school and university? Do you see yourself as an interpreter/translator between K12 students and university faculty?
5. Do you lead/work with students on projects outside of the ones with universities (with other schools? Organizations? Etc.) How are these relationships/experiences similar and different from the university partnerships?
6. What aspects of university partnerships are most impactful?
7. Has being involved in these partnerships help open doors to work on other projects? Please describe.
8. What makes a good partnership between schools and universities? Specifically in rural contexts.
9. What is most important when deciding to work with a University (what would be considered a deal-breaker?)

density compared to the villages served by the schools where Morgan and Ryan teach. Nevertheless, the economic challenges are severe, with 56.2% of students qualifying for free/reduced lunch. Delaney is a [state] Master Teacher, certified to teach 7-12 biology. She has 25 years of teaching experience – 15 years in middle school 8th grade life science, and 10 years in 9th grade living environment (biology) and zoology. Delaney has been in partnership with CU for 14 years, working with the CU-STEP and, more recently, BRAIN-STEM programs. She has also been engaged in other enrichment activities including the Junior Iron Chef Competition, the Wild Program, and has been advisor for the National Junior Honor Society for approximately 8 years.

3.3 Data collection

The sole source of data for this study consists of open-ended survey responses from the teacher participants. Data were collected through extended surveys that were designed by the faculty researchers and administered electronically via Google docs to each of the three teacher-co-authors in December 2024. Survey questions, included in **Table 2**, sought to examine teacher experiences in depth, providing sufficient latitude for teachers to elaborate on specific programs as well as to collect general observations and opinions. Teachers provided responses within a few days of receipt, again through sharing each of their completed Google doc. After an initial read-through by the faculty researchers, teachers were probed for more detail, and subsequently added more depth about the specific programs they were involved in. The entire process of data collection took place over a period of approximately 2 weeks. Our approach to the data collection process followed constructivist grounded theory (Charmaz, 2014), which views researchers as active participants who shape a particular interpretation of the phenomenon being studied (Willig, 2013) and allows for interviews or, in our case, open-ended surveys to be collaborative exchanges through which data can be generated (Mills et al., 2006) and personal experiences can be explored and affirmed (Charmaz, 2014).

3.4 Analysis

Data were analyzed using classical grounded theory methods (Corbin and Strauss, 2015). A coding schema was developed to capture key categories within the teachers' narratives, focusing on the language they used to express their thoughts and experiences. Codes were examined to identify and describe recurring themes across the data sets (Merriam, 2009). The process revealed the various relationships among the stakeholders and components of the K12-university partnerships, enabling us to better understand key criteria for success.

The first three authors independently created initial codes, which were maintained in a dynamic "living codebook" (Reyes et al., 2020) that was continuously updated as new data emerged. The analytical process was iterative. Glaser and Strauss' (1967) grounded theory approach informed analytical processes in the design of the study to analyze and categorize codes that lead to identified themes. The documents were independently coded by the first three authors using; first open coding followed by axial coding. Strauss and Corbin (1998) describe open coding to be a process where "data are broken down into discrete parts, closely examined, and compared for similarities and differences" (p. 102). In the first round, the authors independently coded words and phrases found in the text that appeared related to the research question. As part of the iterative process, the authors met to discuss their open codes, and made note of their similarities and differences. In the next stage, axial coding, the researchers reread the open codes and then grouped codes with similarities together, recognizing them as categories e to their commonalities. Codes were examined to determine their fit within the category they represented. These ideas were coded in a spreadsheet to establish patterns of prevalent themes. Finally, using Strauss and Corbin (1998) constant-comparative method, categories with comparable qualities were combined to identify patterns. These themes and implications are discussed in the following results and then discussion sections. To ensure cross-validity (Patton, 2002) and triangulation of findings (Howe and Stubbs, 2003), the authors met to compare codes, identify similarities, and resolve interpretive discrepancies. The codes were discussed and analyzed collaboratively to identify emerging themes (Strauss and Corbin, 1998). Careful review and adjustment by the broader team of authors, aligning with established practices in qualitative research (Cornish et al., 2014; Richards and Hemphill, 2018), ensured that each code was appropriately categorized.

This process of coding the data and then meeting to discuss and negotiate differing viewpoints of identified themes is a recommended practice in qualitative research analysis (Cornish et al., 2014; Richards and Hemphill, 2018). Themes were established by reading and evaluating the agreed upon codes, then examining for similarities across the codes, and finally by assessing how well it reconciled as an explanation of the data (Castleberry and Nolen, 2018). To further strengthen the analysis, member checks were completed by sharing the data with participants to confirm the participants' experiences were accurately captured. The follow-up communications helped to triangulate the data and confirm

findings (Patton, 2002). The entire process was adapted to enhance trustworthiness, which is essential for conveying the significance of the findings to both readers and researchers (Lincoln and Guba, 1985). Sample codes are presented and defined in **Table 3**, along with the themes they each represent. The data and data analysis, including codes and themes, uncovered a framework to conceptualize the significance of teachers' roles in rural STEMM education systems. The researchers' proposed framework that illustrates the central roles of STEMM teachers is shared in the discussion.

4 Results

The findings are presented below in terms of the themes uncovered during the analysis. The narratives provided deeper insights into intricacies of the relationships between rural schools and universities; the teachers were able to articulate in their own words how they mediated the relationships among students, parents, administration, and university faculty. We should note that most of the responses aligned with overlapping themes where multiple codes could apply. We chose to keep the quotes intact to retain context.

4.1 Environment

All three teachers described geographic isolation, limited access to resources, and the socioeconomic challenges present in their school districts. Ryan's school district is furthest from the CU and has fewer students than the other two:

> Our school district is 1 h and 10 min from CU . . . We have two gas stations, a Dollar General . . . The population was over 450 when I first started 23 years ago with class sizes of 45 students. Recently our district graduated 15 students.

Some students do not have families equipped with resources to support them financially. A typical rural community mindset can be focused on finding a job after graduation rather than pursuing a college degree. As Delaney said, "People in this area tend to have a lower income and I feel that families do not value education . . . Many of my students do not believe they will go to a university or have any interest or family support."

They mentioned students not having reliable access to the internet, the lack of enrichment opportunities, and limited cultural diversity. Ryan stated:

> The major benefit for some of my students is the equipment that can be provided for the student to succeed and to have abilities they would not have prior. The university provided computers and hot spots for my students to do schoolwork, research, and communicate with other staff and students. . .[many] families in our district . . . do not have access to wi-fi. This puts many of them at a disadvantage. I asked for devices and the university provided for multiple families that were involved in the program. The parents were more concerned with providing food and heat. School work was not a priority for some of the families I worked with.

All teachers commented on the difficulty arranging transportation due to the physical distance to campus and a shortage of bus drivers. However, it was repeated many times that campus visits and field trips are a highlight of the student experiences and a key component to the success of the STEMM programing. For example, when asked to elaborate on aspects of a partnership between schools and the university, Morgan said:

> The exposure to the educational institutions in our community is invaluable to students who are otherwise in a very insulated and isolated environment. Many students have never left the county. Some students barely leave their trailers. A disappointing number of students don't play outside. Because of our work with CU, we were included in an energy conference in [nearby small city]. Few of the students had set foot in a hotel/conference center, and I imagine how this kind of exposure might inspire students to broaden their horizons and empower them to pursue their ambitions.

The notion of a strong community due to the smaller populations in rural areas was mentioned by all of the teachers, who each described building long-lasting relationships with the students. Delaney reflected:

> Smaller student populations allow for more personalized learning and attention to students. I feel it is easier to have close knit relationships in a small rural school. There are pros and cons to living in this area and teaching at a rural school.

Also within this theme were stories that described socioeconomic challenges, overcome by that strong community support. Winning teams involved in SSEP had the opportunity to travel to Cape Canaveral to view the rocket launch that was carrying their experiment to the International Space Station. The travel logistics were complicated because the launch date kept changing so plane tickets and hotel reservations needed to be modified repeatedly. The group didn't have much experience traveling much less dealing with the additional stress arising from the uncertainty in the launch itself. In the end, this was a life changing experience for the students and their families, as well as a celebration for the entire community. Ryan elaborated on the experience:

> Everytime the launch was changed the students were very disappointed and I had to encourage them that we would be going. The parents ended up paying over $300 per person for the changed flights. The switch of launches was stressful for families since they had to find care for their animals. The winter months the families also had heating needs and snow removal. This was definitely a learning experience traveling with nine people, Ubers, food allotments, and making our own itinerary. . .Our entire community and school did a send off for us when we went to watch the launch. When we returned

TABLE 3 Codebook sample showing relevant themes, including example codes and definitions for each theme.

Example codes	Code definition
Theme: environment	
Isolation	Rural schools are located far from population centers, and this geographic isolation limits access to resources.
Transportation	Rural areas often suffer from limited or no public transportation, and longer distances can make it difficult to arrange bus transportation.
Lack of family support	Many students lack family support simply because the families are not knowledgeable about or do not value higher education, or the education system in general.
Poverty	Many families live below the poverty line, access to internet or other enrichment opportunities is limited.
Tight community	Many of these lightly populated communities are close-knit, with strong relationships among students, parents, teachers, and community members.
Theme: critical factors	
Communication	Communication between school and university stakeholders is key to successful collaborations, where everyone's voice is heard.
Relationships	Strong relationships between school personnel and college faculty and students contributes toward program success.
Guidance	Teachers provide input and guidance to help faculty understand students' performance levels and interest, and assist with logistics such as materials, scheduling, etc.
Expertise	Quality programs are based on content that leverages expertise of university faculty and students.
Flexibility	Flexibility on the part of university faculty—in terms of content/approach as well as timing—is key to providing quality programing that is accessible to the K12 community.
Theme: positive change (impacts)	
Self-confidence	Students gain confidence to pursue new interests and challenges.
Exposure and engagement in STEM	Students engage in authentic, meaningful STEM experiences in a supportive environment, some have gone on to study STEM after graduating, some have presented their projects to peers and at conferences.
New opportunities for students	In addition to or as part of the STEM outreach programs, students often have the opportunity to attend conferences, visit museums, amusement parks, and other locals that they would never have visited on their own, often exposing them to new, unfamiliar things, broadening their expectations and changing their future.
New opportunities for teachers	Participating in the outreach programs has opened other doors for teachers, including professional development opportunities, learning from University faculty, and at least one successful application to the New York State Master Teacher Program.
Theme: community/network	
Relationships	Partnerships build relationships among teachers, between teachers and students, teachers and faculty colleagues, and between college students and K12 students.
Mentoring	Mentoring relationships develop meaningful connections between college and K12 students, as well as between university faculty and K12 teachers.
Teacher-teacher connections	Teachers appreciate the opportunities to develop networks, with teachers at their own school and in other districts.

> we had a school-wide assembly to share our experience with preK12 students. The experience was not just the participants', it is the entire school's success. Academics tend to be under celebrated in small schools and we tend to celebrate sports. The heart of the community is the schools.

> The groups had multiple interviews with local TV and newspapers. These had to be done during classes. The times were scheduled by the media professionals, so we had to be flexible and accommodating. We had a lady donate $200 dollars to our school for supplies. We all have jackets, with the patch that was designed for their mission. Both groups were asked to go and present our experience to the County Legislators. . .All five students and myself were presented with a certificate of recognition.

4.2 Critical factors

We identified several critical factors that contribute to the success of the university partnerships. These included strong relationships with the college faculty and students, high quality program content, and effective communication.

The teachers identified that campus visits were important because it was a change of environment for the students. In particular, there are few opportunities for them to interact with college students. A shared goal across all the STEMM programs is for student participants to see themselves as capable of doing STEMM. Key to the success of the campus visits and afterschool programing is the active involvement of college student mentors who assist during the activities. Morgan talked at length about one graduate student, [Gretchen], who assisted with SSEP and with whom she developed a long-standing relationship:

> The following year, [Gretchen] presented on her work with primates in Africa at one of our weekly lunch meetings. This past spring, she organized a Green Team Youth Climate Summit at the Wild Center. Our Green Team students in grades 5-8 are not eligible for the Center's official Youth Climate Summit, so Gretchen assisted us, creating an opportunity for about 80 students, faculty and parent chaperones to have our very own. Students learned how to create a climate action plan. . .CU students are inspiring role models who bring fresh and vibrant energy to engage the students in meaningful activities.

Quality programing was also a factor that contributes to success. Morgan continued: "The professors I've worked with bring a wealth of knowledge and expertise, have been highly organized, and have communicated effectively with their students and me to optimize the collaborative efforts."

In fact, communication is a priority in our programs, and part of what leads to quality programing is that teachers are true partners in activity design and implementation. Teachers and faculty in CU-STEP, which has been running for 19 years, are comfortable and confident sharing new ideas. They are a team whose goal is to create impactful learning experiences for the student participants and as a result, the program is constantly evolving.

Flexibility on the part of university faculty is also key to providing quality programing and meaningful experiences for students. BRAIN-STEM, which was modeled after CU-STEP, is in its beginning phase. When the first BRAIN-STEM camp took place, teachers and faculty had only met twice earlier that semester so there was not sufficient time to build trust or really get to know each other. The general plan and overview of the content of the camp was reviewed, but because of the timing of the grant, the first camp took place before the teachers could effectively immerse themselves in the activities. Moreover, the CU team had never worked together before in this capacity (with the exception of Delaney who worked with CU-STEP for roughly 14 years). At the camp, the student participants were not engaged. At the end of the first day, many expressed to their teachers that they didn't want to come back. Faculty quickly realized the need to overhaul what they were doing. Although the camp ended on a positive note, the experience was an enlightening one for the new faculty leading the program. For example, they realized that the CU college mentors were underutilized and should have been more front and center during the delivery of the curriculum. Despite the teachers consistently saying that students needed to get up and move more with hands-on activities, the days still tended toward more of a lecture style. Now well into the afterschool program, the neuroscience content is the same, but the curriculum and activities are structured and presented completely differently thanks to input from the teachers. The teachers appreciate being included in the process and the faculty appreciate the guidance on how to make their content relatable to young learners. Delaney describes:

> The professors at CU are always asking the students and teachers how they can make the program better and stress how much they value our opinions. They actually take our suggestions and put them into action. That makes us feel valued and an important part of the success of the program.

Ryan also noted that true collaboration contributes to success and that she views communication as part of her role in the partnership:

> Communication is the most important factor. Sometimes not everyone is on the same page but when we collaborate it starts more discussions to make the programs better for us and the students to succeed. When everyone has a say or is allowed to participate in the development of programs, they tend to be more accepted and create a community of learning.

> My role is the connection between school and university. I provide a lot of feedback to my school body on how important these programs are for our students. The opportunities that allow them to feel confident to present to people. . .I advocate for students that do not have the opportunities of others. They are not allowed an equal playing field for college acceptance or job opportunities. The partnership allows them information and access to resources to help them emotionally and mentally to succeed. College is an option for them, and they can do math and science outside the traditional classroom setting.

4.3 Positive change

The teachers' narratives highlighted numerous positive impacts on students as well as themselves. The interaction with CU students and faculty, the time spent on a college campus or on a field trip, the hands-on curriculum and STEMM competitions, and the relationship building were all identified as contributing factors. All teachers said they observed changes in their students' confidence. Morgan shared:

> The students connect to and identify with the [university] students who come to work with them. They are inspired, invigorated, and empowered by the opportunities the universities provide. For instance, SSEP provided an opportunity to engage in real-world scientific inquiry, work collaboratively with peers, university students, faculty and staff, as well as experts in the field. These experiences and connections are authentic and meaningful, and having those experiences in a supportive environment allows students to build the confidence to pursue their interests, maintain academic connections, and forge new ones in the future.

And according to Delaney:

> This program has given them social connections, increased confidence, and allowed them to step out of their comfort area and try new things. I will be forever grateful for what these programs have given to my students. I would never

> have stayed for the past 18 years if I did not LOVE the staff that I work with at CU. They are truly the most caring, flexible, passionate people and I consider them my friends. They make this partnership a catalyst for change and create meaningful learning experiences for students that have limited opportunities. The monthly CU visits introduce students to complex problems that stimulate their curiosity. They offer my students hands-on learning experiences that are crucial to their understanding. They [the students] communicate and collaborate with their team members while at the same time are very creative and do not realize they are critically thinking at the same time.

Highlighting the students' achievements brings the community together. It also sparks interest in other students to engage in STEMM. The participating students develop professional and life skills and demonstrate growth when in a new environment. By immersing themselves in authentic STEMM, they see themselves as going not only to college, but to top colleges. They can identify with STEMM because they have experienced it. According to Ryan:

> Since CU offers us help in every step of the way with these challenges the students are involved with, it creates a positive impact on the students. The students feel successful and confident when they are asked to share what they have done. Partnership success is the students' success and needs to be shared in our district newsletter and community posts. The accomplishments of the students involved in these activities have encouraged others to want to be involved. In this partnership with the university, I get to see a lot of my students in such different roles (at home district they were troublemakers and very disrespectful and at the university were role models for our students and students from other districts).

> This was a difficult task for me, the students were amazing doing their research and mini experiments to test their ideas. I am extremely proud of our scholars and how they took the challenge and developed the experiments and we were self-motivated. The world is science and they proved they could do it, when given the opportunities. All students involved were really in it to win it. They were not in the classroom setting but were being challenged in a way they felt allowed them to create their own piece of science.

> Student's DNA went to space, so it was like they were also sent to the International Space Station, very exciting to them when they realized this. Fingerprints were on the tubes. The students involved would not have been able to experience this on their own. With the support from CU, many of my students over the years have increased their self-worth and have a more positive outlook. Some now say "I am going to try to get into MIT". [one student] did get accepted! Being able to use her experiences with the program SSEP, helped her stand out. One student is in college studying aerospace engineering- she has been asked to work with NASA, one is mechanical engineering, one is still a junior in high school taking Chemistry.

Delaney's involvement with the university partnership supported her career pathway. She has met other teachers to collaborate with, co-developed new curriculum to use in the classroom, and deepened her own scientific knowledge:

> Partnering with a university has allowed me to collaborate with professors and teachers in my field allowing me to grow and gain new expertise in my field. It has made me a better person and teacher. I have been impacted by this program just a much as my students. Many of the teachers/staff are now my close friends. I enjoy the campus visits and field trips for my students and because I can spend time with some amazing people that care about kids as much as I do. My affiliation with this program was a key factor in being chosen for the NYS Master Teacher program. They encourage teachers to be involved in STEMM as much as possible. I am very grateful for this opportunity because it has opened other doors for me. I was able to travel to Baja Mexico and participate in a marine ecosystem professional development course and to the San Diego Zoo Safari Park for another week long professional development class that I would have never been able to do on my own. CU STEMM programs have not only opened doors for my students but for me as well.

4.4 Community/network

Echoed throughout the narratives was the theme that the university partnership was key to building lasting, meaningful relationships resulting in a strengthened sense of community and a network to leverage for professional growth. Teachers built friendships with teachers from other school districts they otherwise would not have met. They had networking opportunities to discuss shared classroom challenges and potential solutions with peers outside of their school. Delaney shared:

> I was able to meet five other local teachers in the area that have become some of my closest friends. We have been able to collaborate with each other and discuss many educational and personal topics of interest. Building a network of colleagues is so important in this time of my career as the state is changing our living environment (biology) regents and curriculum for the first time in my 25 years.

Morgan's partnership with CU helped them make other community connections that supported their Green Team curriculum:

> Most recently, due to our connection with [the local extension service], the Food-to-Energy Project . . ., [extension educator] connected us with [a nearby school's] Greenhouse Program.

> They plan to do a field trip in which we connect to share information related to our efforts related to food waste management, inspired by our work with . . . the Food-to-Energy Project. These connections will extend to our work with [another community organization]—another collaboration that has roots in the Food-to-Energy Project.

> In one instance, the bus driver who was delivering our SSEP group to CU inquired about the purpose of our trip. When he learned about the connection with NASA and the students' interest in the space program, he shared that he was an amateur radio operator, offered to present to the Green Team, and offered the chance to contact the ISS! We hoped to follow through with this near the time of the solar eclipse, but the logistics were not in our favor, yet we maintain a connection and will seek future opportunities to follow up.

All teachers commented on how students benefited from building relationships with college students, faculty, and students from other schools, but students and teachers also strengthened their relationships by participating in the program together. Delaney shared:

> The main reason I find the time is of course my students. When I see how much fun they have at the university meetings and field trips it makes me want to continue to help them and this program in any way I can. Because the university projects have a longer timeline it allows me to build a relationship with the students even more than in my regular classes. In my first year in CU-STEP, I had a student that I worked with on an almost daily basis for months. He created a rollercoaster to compete in the competition at CU. He became like a son to me and I would bring him places with my own children outside of school. This is only one of the bonds I have created with my IMPETUS students. This program allows me to get closer to my students and create those relationships that last a lifetime.

And according to Ryan:

> The biggest challenges can be overcome when all work as a team. All the students were willing to complete the proposals and saw the results. When students are given opportunities they will excel. I am glad to be a part of giving them the experience/opportunity/chance for change/success they will never forget and help them grow and become a better community success.

Strong relationships between faculty and teachers are critical to the future success of emerging programs. From a faculty's perspective, teachers provide invaluable feedback on new grants or programing ideas. Having a teacher-partner at a school district helps get buy-in from building leaders to implement new STEMM enrichment opportunities. Working together is key. For example, monthly meetings for the CU-STEP program are held with all stakeholders to review program components, discuss progress, and problem solve. We also look for new ideas to engage and support the students. There is trust and a comfortable environment so that anyone feels that their ideas should be heard. The faculty hear about new learning standards, the emotional health of K12 students, and the challenges teachers are experiencing so that they can brainstorm ways to help. Ryan said:

> The professors and staff that I work with at CU are one of the main reasons I find the time. They are compassionate and enthusiastic about teaching the love of STEMM to my students and offering them opportunities they would never have without them. I have also been able to experience first-hand how professors are changing their pedagogy to a more inquiry-based learning environment. This has been helpful as a high school teacher to learn what will be expected of my college-bound students.

5 Discussion

Overall, our findings uncovered important details concerning the relationships among the various stakeholder groups, which we describe using the framework shown in **Figure 1**. Teachers are the essential component, playing the central role of Cultural Navigators (CNs). Not only do they connect their students with the University Partners and programs, they also serve as advocates – supporting and facilitating relationships among all key stakeholders. The idea of Cultural Navigators is described more fully in section 5.2. As CNs, teachers act as translators and intermediaries to create successful partnerships in rural areas. Below, we answer the proposed research questions and highlight the analyses that support this framework.

5.1 RQ1: what are the unique assets and challenges among our higher education-K12 rural partnerships?

Higher education and K12 rural partnerships bring both unique strengths and challenges. For example, as shared by the teachers, the rural environment was both a strength and challenge for this community. Rural areas have strong community ties (Luo et al., 2022), and the relatively small classroom size and student population allows for more individualized teacher-student interaction and for teachers to get to know their students' families, supporting the idea that teachers are central to this relationship (**Figure 1**). However, rural environments create challenges, including isolation and transportation issues, that limit students' access to resources and experiences. Rural communities and schools also tend to have fewer financial resources (Mathis, 2003) and experience higher levels of teacher shortages. In addition, there is often a disconnect between faculty and local school districts that inhibits meaningful partnerships. Based on our data and the literature reviewed, teachers are essential in overcoming this disconnect.

While it is impossible to document all the ways university-partnerships make a difference, all of the programs in this

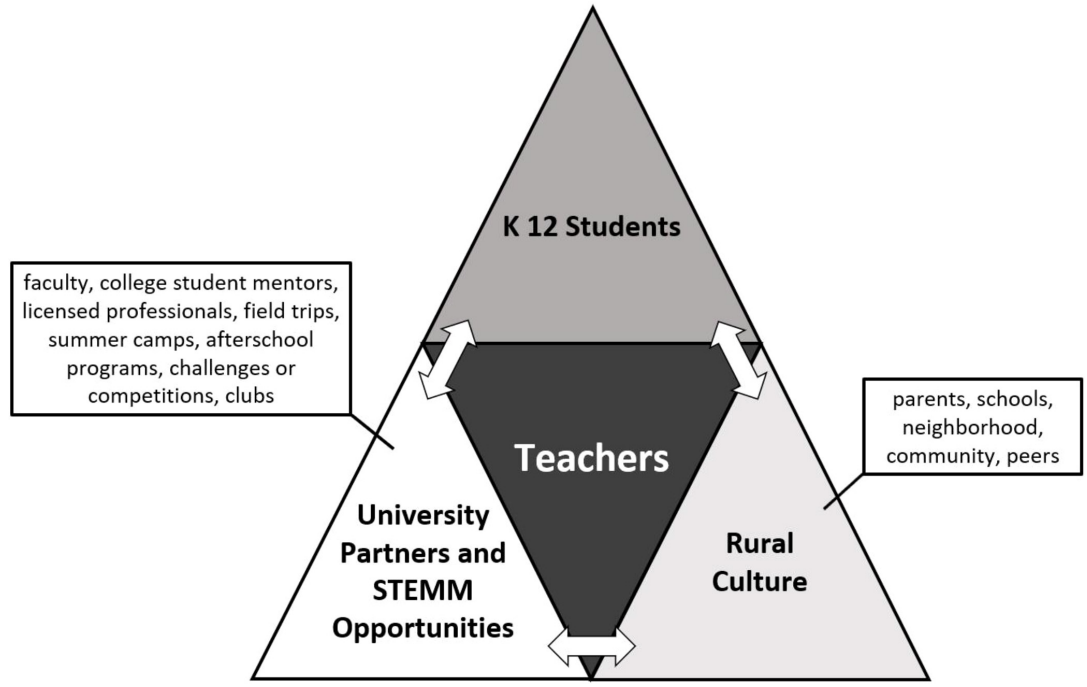

FIGURE 1
Proposed theoretical framework.

study included components (Table 1) to help alleviate these challenges. Teachers also overcome their own isolation through participation in these programs. Delaney's involvement with CU STEP and BRAIN-STEM supported her career pathway. She has met other teachers to collaborate with, co-developed new curriculum, and became a Master Teacher. Morgan built other community partnerships through Food-to-Energy that supported her career and expanded the programing in her after school Green Team.

All four programs provided engaging STEMM curriculum, giving students experiences they otherwise never would have had. All teachers unanimously described how campus visits and afterschool programs with college student mentors improved students' STEMM identity and confidence. Ryan noted that students involved with CU STEP who were often troublemakers in their own school districts were role models while on campus.

Faculty learn from the teachers through all of these programs, which are designed to be collaborative between the faculty and teacher partners. Faculty become aware of new learning standards, the social-emotional health of K12 students, and the challenges teachers are experiencing, which helps faculty better understand their future students. In the end, this may help them appreciate that their future students are continuously learning and growing. Providing space for university faculty to work with teachers strengthens the partnerships, and also helps faculty to spend some focused time on students and pedagogy.

Table 4 describes the specific learning needs, assets, and challenges we have focused on throughout this study and explicitly describes how these four university partnership programs aim to support students and teachers.

Still, much of the work required to build a successful partnership is dependent on teachers' ability and willingness to spend extra time to "cross borders" between the various components or stakeholders described in Figure 1, creating a bridge between their students, the rural communities in which they live and work, and the university faculty and STEMM programing opportunities they are engaged in. They also have to build relationships with STEM faculty who are receptive and open to allowing teachers to lead this work, essentially supporting teachers' roles.

5.2 RQ2: what are the lessons learned from engaging in this work?

Communication is a critical factor to the success of university-school partnerships, and to that end, teachers play a prominent role. Through their narratives it became clear that teachers are Cultural Navigators (CNs) among the various stakeholders in a university-school partnership in a rural setting. As described by a program established at Hartford Public library, CNs act as mentors who ease cultural adjustment, strengthen connections to essential services and resources, and facilitate community engagement and family activities (Hartford Public Library, n.d.; Thomas et al., 2016). Essentially, a CN is a skilled communicator and cultural interpreter who helps individuals and groups navigate the complexities of intercultural interactions. They possess a deep understanding of the cultures involved and can effectively communicate and translate cultural nuances to promote positive interactions. Thus we see in our teachers the role of navigating among the various stakeholders that make the partnerships thrive. The double headed arrows on

TABLE 4 Program assets.

	CU discovery space	BRAIN-STEM	CU STEP	Food-to-energy
Learning needs: access to resources, role models, STEM experiences, sense of belonging/identity	Curriculum in microgravity and the scientific method, college student/faculty mentors, team work to proposal a real research experiment	Curriculum in neuroscience and the scientific method, hands-on activities, college student/faculty mentors, team work on final project	Wide range of activities and challenges to engage students in hands on STEM (ex; drones, robotics, coding), college mentors, long term commitment (7-12th grade)	Project-based, place-based lessons taught in science classroom and afterschool programing promote STEM learning, exposure to sustainability topics, and sense of agency; college student mentors are role models
Assets: strong community ties, close teacher-student relationships	Community celebration of success, teachers and families traveling together	Teachers leading the afterschool program and attending all campus events together, interaction with rural health care professionals	Long term teacher coaches, the program has existed for nearly 20 years, teachers taking students to statewide conference, parents attending award ceremonies, recognition dinners, and advisory board meetings.	Program connects school students and faculty to additional resources in community and fosters close university/school relationship
Challenges: isolation, financial constraints, inadequate facilities/resource, disconnect between college and rural culture	Campus visits, access to campus lab and supplies, school visits by college student/faculty mentors, travel to rocket launch with teacher, family, and college mentor.	Campus visits, school visits by college mentors, experiences in health science labs, teachers guiding curriculum development and delivery	Campus visits, field trips, equipment/laptops lent to students, school visits by college student/faculty mentors, teachers guiding curriculum development and delivery	Field trips, graduate student support for school and cafeteria programing, curriculum development and delivery, teacher professional development opportunities

Figure 1 highlight how the connections among the components all include the teachers as CNs.

According to Thomas et al. (2016), CNs are supportive advocates who help build connections within their community. They are knowledgeable about the differing characteristics of the people involved so they are equipped to reduce misunderstandings and facilitate communications. In the context of this research, teachers have the cultural capital to guide students through all the STEMM community components as well as facilitate communications with university partners, parents, and their own building leaders. They have gone to college so they are familiar with a university setting; they have discipline specific STEMM expertise similar to faculty; they live in the same geographically isolated area as their students and parents; and they understand the operations of their school administration.

From our experiences, when faculty try to initiate partnerships with school districts they often fail because they lack buy-in, have unrealistic expectations, and/or limited experience teaching complex ideas to young learners. However, building a strong relationship with a teacher who can work with them to understand classroom constraints, develop realistic activities, and promote their event or program can result in a successful experience for everyone involved. Teachers need to be involved in the curriculum development process before it is used in schools.

This study revealed that effective university-school partnerships can overcome challenges inherent in rural schools. Building relationships between faculty and teachers is key. Effective partnerships are fostered by open communication, collaboration, and agency among all stakeholders. University-school partnerships can come in varying forms ranging from 1-day field trips to after school programs to summer STEMM camps. Important elements of programing include campus visits, co-designed curriculum, and multiple opportunities for interaction with college students.

Partnerships between universities and rural schools are highly complex and should not be treated as a uniform group. Instead, they should be studied to understand how programs can be tailored to address the specific needs of rural and non-rural communities. Successful partnerships between universities, schools, and communities require mutual understanding and collaboration to meet the diverse needs of students and families while also providing training and awareness to the college community involved. This unique work to support successful partnerships includes teachers as a core component (see Figure 1). As Biddle and Azano (2016) note, "Advocacy for the importance of rural within education is not enough–researchers must explore the intersection of rural realities with diverse socio-spatial contexts in the era of 21st-century globalization" (p. 317). This study supports Tomanek (2005) idea that effective K12-university partnerships do not start with university faculty imposing changes on K12 classrooms but instead, faculty emerge in response to the specific needs identified by practicing teachers for their students and curricula. Also, the most effective curricular improvements come from individuals who possess both scientific expertise and a deep understanding of the school learning environment. Lastly, successful partnerships encourage university faculty to consider how engaging with K12 schools and teachers can enrich the education of their own students.

One of the primary goals across all our programs is to foster a sense of belonging and self-agency in the student participants so that they can see themselves as someone capable of applying STEMM principles in their lives. Each stakeholder has a role in overcoming barriers and helping to ensure programs are inclusive, supportive, and capable of promoting student success. Teachers are vital to the success of rural university partnerships because they have the cultural capital to navigate to other key stakeholders (Figure 1). Faculty are not likely able to necessarily get "in"

to the other systems shown in Figure 1, but teachers can lead other stakeholders through to build a broader sense of community.

6 Conclusion, limitations, and future directions

Our major finding is that teachers are a central component to the success of rural STEMM partnerships between higher education and K12 schools. However, our findings should be considered in light of several limitations. Although the Institute for STEM Education operates long-term programing with dozens of teachers, only three were included as collaborators in this research. Moreover, all three teachers have a long history of partnerships with CU and are the same gender and race. It is likely that a more diverse group of collaborators might have offered a broader range of perspectives, which should be considered in future studies. This research did not include a comparison group such as the inclusion of faculty or teachers who have not participated in university-school partnerships. To this end, the findings presented here are representative of our own successful programing, and may or may not be unique to these specific partnerships. While rural areas have commonalities amongst each other, each area may have distinctive characteristics; this study represents just one rural area in the United States. Finally, no student, parent, or school administrator information was considered. Certainly looking at changes in student attitudes or grades, or collecting narratives from parents, would provide different viewpoints and perhaps identify additional contributing factors. To build on this research, we propose studies with larger, more diverse samples, including demographic groups and rural areas in different parts of the country, comparison groups, and multiple stakeholder perspectives. Future studies should consider using quantitative methods alongside qualitative methods for a more comprehensive understanding of what contributes to the success of university-school partnerships and to identify the metrics for success.

Data availability statement

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

Author contributions

SR: Writing – original draft, Writing – review and editing, Formal Analysis, Methodology. KK: Writing – original draft, Writing – review and editing, Formal Analysis, Investigation, Methodology. JD: Writing – original draft, Writing – review and editing, Formal Analysis, Investigation, Methodology. MR: Writing – original draft, Writing – review and editing. LB: Writing – original draft, Writing – review and editing. LJ: Writing – original draft, Writing – review and editing. NT: Writing – original draft, Writing – review and editing. MS: Writing – original draft, Writing – review and editing. LB: Writing – original draft, Writing – review and editing, Conceptualization, Investigation.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was funded by the NYS Education Department Science and Technology Entry Program GC25-001, Science Education Partnership Award funded by the National Institute of General Medical Sciences (NIGMS) of the National Institutes of Health (NIH) 1R25GM150156-01, Corning Foundation. Food-to-Energy project funded by 4 consecutive grants from Constellation, an Exelon Company, through their Constellation E2 Energy to Educate grant program.

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 Generative AI was used in the creation of this manuscript.

Publisher's note

References

Allan, B. A., Garriott, P. O., and Keene, C. N. (2016). Outcomes of social class and classism in first- and continuing-generation college students. *J Couns Psychol.* 63, 487–496. doi: 10.1037/cou0000160

Biddle, C., and Azano, A. P. (2016). Constructing and reconstructing the "rural school problem" a century of rural education research. *Rev. Res. Educ.* 40, 298–325. doi: 10.3102/0091732X16667700

Boynton, M., and Hossain, F. (2010). Improving engineering education outreach in rural counties through engineering risk analysis. *J. Professional Issues Eng. Educ. Pract.* 136, 224–232. doi: 10.1061/(asce)ei.1943-5541.0000026

Brenner, D. (2016). Rural education and the every student succeeds act. *Rural Educ.* 37:271. doi: 10.35608/ruraled.v37i2.271

Bryan, L., and Guzey, S. S. (2020). K-12 STEM education: An overview of perspectives and considerations. *Hellenic J. STEM Educ.* 1, 5–15. doi: 10.51724/hjstemed.v1i1.5

Burrows, E., Suh, R., and Hamann, D. (2012). *Health Care Workforce Distribution and Shortage Issues in Rural America*. Kansas City: National Rural Health Association.

Byun, S., Meece, J. L., and Irvin, M. J. (2012). Rural-nonrural disparities in postsecondary educational attainment revisited. *Am. Educ. Res. J.* 49, 412–437. doi: 10.3102/0002831211416344

Castleberry, A., and Nolen, A. (2018). Thematic analysis of qualitative research data: Is it as easy as it sounds? *Curr. Pharm. Teach. Learn.* 10, 807–815. doi: 10.1016/j.cptl.2018.03.019

Charmaz, K. (2006). *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. Thousand Oaks, CA: Sage.

Charmaz, K. (2014). *Constructing Grounded Theory*, 2nd Edn. Thousand Oaks, CA: Sage Publication.

Corbin, J., and Strauss, A. (2015). *Basics of Qualitative Research*. Thousand Oaks, CA: SAGE Publications.

Cornish, F., Gillespie, A., and Zittoun, T. (2014). "Collaborative analysis of qualitative data," in *The Sage Handbook of Qualitative Data Analysis*, ed. F. Uwe (London: Sage), 79–93.

DeWaters, J. E., and Grimberg, S. J. (2021). "Food to energy: A K12/university partnership to develop a resource recovery program," in *Proceedings of the 128th Annual ASEE Virtual Conference & Exposition, July 2021. Paper ID #23605. Awarded ASEE Best Paper, ECCD (Energy Conversion & Conservation Division)*, (ECCD).

DeWaters, J., and Grimberg, S. J. (2022). Food waste-to-energya et al., 2020" "Staus et al., 2020.": A project-based school learning experience. *ResearchOutreach* 128. doi: 10.32907/RO-128-2236048339

DeWaters, J., Rivera, S., Kavanagh, K., Galluzzo, B., Pacht, A., and Ramsdell, M. (2025). *Clarkson's Institute for STEM Education PK-12 Partnerships in Boundary-Spanning in School-University Partnerships*. Charlotte, NC: IAP Publishing.

Dolan, E. L., Soots, B. E., Lemaux, P. G., Rhee, S. Y., and Reiser, L. (2004). Strategies for avoiding reinventing the precollege education and outreach wheel. *Genetics* 166, 1601–1609. doi: 10.1534/genetics.166.4.1601

Fowler, K. R., and Turner, P. (2010). "A holistic approach to applied mathematics education for middle and high schools," in *Proceedings of the ICMI/ICIAM Conference on Educational Interfaces Between Mathematics and Industry, Lisbon*, (Portugal).

Glaser, B. G., and Strauss, A. L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Piscataway, NJ: Rutgers.

Gray, B., Johnson, T., Kish-Gephart, J., Tilton, J., Lawrence, T., Amis, J., et al. (2018). Identity work by first-generation college students to counteract class-based microaggressions. *Organ. Stud.* 39, 1227–1250. doi: 10.1177/0170840617736935

Harris, R. S., and Hodges, C. B. (2018). STEM Education in Rural Schools: Implications of Untapped Potential. *Natl. Youth Risk J.* 3, 3–12. doi: 10.20429/nyarj.2018.030102

Hartford Public Library (n.d.). *We Belong Here: An Initiative for Immigrant and Community*. Available online at: http://www.hplct.org/assets/uploads/files/HPL_We%20Belong%20Here%20Toolkit.pdf

Howe, A. C., and Stubbs, H. S. (2003). Science teacher to teacher leader: Leadership development as meaning making in a community of practice. *J. Sci. Educ.* 87, 281–298. doi: 10.1002/sce.10022

Kavanagh, K., DeWaters, J., Rivera, S., Richards, M., Ramsdell, M., and Galluzzo, B. (2022). A University-community partnership model to support rural STEM teaching and student engagement. *Theory Pract. Rural Educ.* 12, 229–248. doi: 10.3776/tpre.2022.v12n2p229-248

Kelly, K. L. (2016). Engaging rural Appalachian high school girls in college science laboratories to foster STEM-related career interest. *J. Microbiol. Biol. Educ.* 17, 77–80. doi: 10.1128/jmbe.v17i1.996

Kline, J., and Walker-Gibbs, B. (2015). Graduate teacher preparation for rural schools in victoria and Queensland. *Australian J. Teach. Educ.* 40, 68–88. doi: 10.14221/ajte.2014v40n3.5

Kokotsaki, D., Menzies, V., and Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools* 19, 267–277. doi: 10.1177/1365480216659733

Lent, R. W., Brown, S. D., and Hackett, G. (2000). Contextual supports and barriers to career choice: A social cognitive analysis. *J. Counseling Psychol.* 47, 36–49. doi: 10.1037/0022-0167.47.1.36

Lichter, D. T., and Brown, D. L. (2011). Rural America in an urban society: Changing spatial and social boundaries. *Annu. Rev. Sociol.* 37, 565–592. doi: 10.1146/annurev-soc-081309-150208

Lincoln, Y. S., and Guba, E. G. (1985). *Naturalistic Inquiry*. Thousand Oaks, CA: SAGE Publications.

Lozo, K., Mondal, S., Fowler, K. R., and Brydges, B. (2011). A mathematical modeling approach to understanding the impact of STEM institutes on building teachers leader. *Int. J. Arts Sci.* 4, 9–18. doi: 10.37418/stem.1.12

Luo, X. I., Hipp, J. R., and Butts, C. T. (2022). Does the spatial distribution of social ties impact neighborhood and city attachment? Differentials among urban/rural contexts. *Soc. Netw.* 68, 374–385.

Maltese, A. V., and Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Sci. Educ.* 95, 877–907. doi: 10.1002/sce.20441

Mathis, W. J. (2003). Financial challenges, adequacy, and equity in rural schools and communities. *J. Educ. Finance* 29, 119–136.

Means, D. R. (2019). Crucial support, vital aspirations: The college and career aspirations of rural Black and Latinx middle school students in a community- and youth-based leadership program. *J. Res. Rural Educ.* 35, 1–14. doi: 10.18113/P8JRRE3501

Merriam, S. B. (2009). *Qualitative Research: A Guide to Design and Implementation*. San Francisco, CA: Jossey-Bass.

Mills, J., Bonner, A., and Francis, K. (2006). Adopting a constructivist approach to grounded theory: Implications for research design. *Int. J. Nurs. Pract.* 12, 8–13. doi: 10.1111/j.1440-172X.2006.00543.x

Mitchell, C. J. (1984). "Case studies," in *Ethnographic Research: A Guide to General Conduct*, ed. R. F. Ellen (London: Academic Press), 237–241.

Morton, T. R., Ramirez, N. A., Meece, J. L., Demetriou, C., and Panter, A. T. (2018). Perceived barriers, anxieties, and fears in prospective college students from rural high schools. *High School J.* 101, 155–176. doi: 10.1353/hsj.2018.0008

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods*, 3rd Edn. Thousand Oaks, CA: Sage Publications.

Peterson, B., Bornemann, G., Lydon, C., and West, K. (2015). Rural students in Washington State: STEM as a strategy for building rigor, postsecondary aspirations, and relevant career opportunities. *Peabody J. Educ.* 90, 280–293. doi: 10.1080/0161956X.2015.10223

Powers, S. E., and DeWaters, J. (2004). "Creating project-based learning experiences for university- K-12 partnerships," in *Proceedings: IEEE Frontiers in Education Annual Conference*, (IEEE), 18–23.

Powers, S. E., Brydges, B., Turner, P., Gotham, G., Carroll, J. J., and Bohl, D. G. (2008). "Successful institutionalization of a K-12 - University STEM partnership program," in *Proceedings of the 115th Annual ASEE Conference & Exposition*, (Pittsburgh PA).

Reagan, E. M., Hambacher, E., Schram, T., McCurdy, K., Lord, D., Higginbotham, T., et al. (2019). Place matters: Review of the literature on rural teacher education. *Teach. Teach. Educ.* 80, 83–93. doi: 10.1016/j.tate.2018.12.005

Reyes, V., Bogumil, E., and Welch, L. E. (2020). *The Living Codebook: Documenting the Process of Qualitative Data Analysis*. Available online at: https://doi.org/10.31235/osf.io/gvcsm (accessed November 13, 2020).

Richards, K. A. R., and Hemphill, M. A. (2018). A practical guide to collaborative qualitative data analysis. *J. Teach. Phys. Educ.* 37, 225–231. doi: 10.1123/jtpe.2017-0084

Rivera, S., Knack, J., Kavanagh, K., Ramsdell, M., and Thomas, J. (2019). Building a STEM mentoring program in an isolated, economically disadvantaged, rural community. *J. Educ. Res. Pract.* 9, 413–422. doi: 10.5590/JERAP.2019.09.1.29

Saw, G. K., and Agger, C. A. (2021). STEM pathways of rural and small-town students: Opportunities to learn, aspirations, preparation, and college enrollment. *Educ. Res.* 50, 595–606. doi: 10.3102/0013189X211027528

Schafft, K. A. (2016). Rural education as rural development: Understanding the rural school-community well-being linkage in a 21st-century policy context. *Peabody J. Educ.* 91, 137–154. doi: 10.1080/0161956X.2016.1151734

Silva-Peña, I., Precht, A., O'Brien, T. V., and Jara, C. (2020). Far away, but yet so close. Urban teacher education and rural schools: Directors' point of view. *Int. J. Inclusive Educ.* 26, 1–15. doi: 10.1080/13603116.2020.1772892

Simpson, A., and Bouhafa, Y. (2020). Youths' and adults' identity in STEM: A Systematic literature review. *J. STEM Educ. Res.* 3, 167–194. doi: 10.1007/s41979-020-00034-y

Stebleton, M. J., Lee, C. K., and Diamond, K. K. (2020). Understanding the food insecurity experiences of college students: A qualitative inquiry. *Rev. High. Educ.* 43, 727–752. doi: 10.1353/rhe.2020.0005

Strauss, A., and Corbin, J. (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, CA: Sage Publications, Inc.

Thomas, R. L., Chiarelli-Helminiak, C. M., Ferraj, B., and Barrette, K. (2016). Building relationships and facilitating immigrant community integration: An evaluation of a Cultural Navigator Program. *Eval. Program. Plann.* 55, 77–84. doi: 10.1016/j.evalprogplan.2015.11.003

Tomanek, D. (2005). Building successful partnerships between K-12 and universities. *Cell. Biol. Educ.* 4, 28–37. doi: 10.1187/cbe.04-11-0051

Tran, H., Hardie, S., Gause, S., Moyi, P., and Ylimaki, R. (2020). Leveraging the perspectives of rural educators to develop realistic job previews for rural teacher recruitment and retention. *Rural Educ.* 41, 31–46. doi: 10.35608/ruraled.v41i2.866

Turner, P., Fowler, K., Wick, D., Ramsdell, M., Gotham, G., Glasgow, E., et al. (2007). "BOCES-University Partnership as a model for Educational Outreach: K-16 STEM professional development," in *Proceedings of the Inaugural Math and Science Symposium*. Knoxville, TN.

U.S. Department of Education, National Center for Education Statistics (NCES). (2025). *Digest of Education Statistics*. Available online at: https://nces.ed.gov/surveys/annualreports/topical-studies/locale/definitions.

Ufnar, J. A., and Shepherd, V. L. (2018). The scientist in the classroom Partnership program: An innovative teacher professional development model. *Professional Dev. Educ.* 45, 642–658. doi: 10.15695/jstem/v3i3.06

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *Am. Educ. Res. J.* 50, 1081–1121.

Weiss, M. P., Rowe, D. A., Mims, P. J., and Farmer, T. W. (2023). There's no place like us: Beyond fidelity of implementation in rural contexts. *J. Emot. Behav. Disord.* 31, 154–167. doi: 10.1177/1063426623115 5856

Wick, D. P., Ramsdell, M. W., Fowler, K., Turner, P., and Schalk, P. D. (2011). "University outreach in STEM education through a Roller Coaster Science and Engineering Camp," in *Frontiers in Education Conference (FIE)*, pp. S3D-1. Piscataway, NJ: IEEE.

Willig, C. (2013). *Introducing Qualitative Research in Psychology*, 3rd Edn. Milton Keynes: Open University Press.

Yin, R. K. (2014). *Case Study Research: Design and Methods*, 5th Edn. Thousand Oaks, CA: Sage Publishing.