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STEM Teaching and Learning in Rural Communities: Exploring Challenges and Opportunities An Introduction to Volume 12, Issue 2 of TPRE

Janet K. Stramel and **Earl Legleiter,** Fort Hays State University

This special issue of *Theory & Practice in Rural Education* highlights STEM Teaching and Learning in Rural Communities. The articles selected represent both theory and practice and explore the complexities, practices, challenges, and opportunities facing rural schools and universities as they design and implement STEM teaching and learning. Articles from the field have related rural school success stories of how rural districts have overcome challenges to have effective and rich STEM teaching and learning in rural schools.

***Keywords*: STEM teaching, rural education**

This special issue of *Theory & Practice in Rural Education* highlights STEM Teaching and Learning in Rural Communities. The articles selected represent both theory and practice and explore the complexities, practices, challenges, and opportunities facing rural schools and universities as they design and implement STEM teaching and learning. Articles from the field have related rural school success stories of how rural districts have overcome challenges to have effective and rich STEM teaching and learning in rural schools. Article submissions crossed a variety of topics, and three main themes emerged throughout the articles: (1) making STEM teaching relevant, (2) promising practices, and (3) professional development. While rural educators and communities face unique challenges, they can also provide many opportunities such as the knowledge, experiences, and local connections that can strengthen STEM education. When the complexities of rural spaces are acknowledged, collaborative partnerships can bring external and internal assets together to meet those challenges and boost STEM learning and teaching in rural schools.

Located on the Fort Hays State University campus in rural western Kansas is a one room schoolhouse from another century that was disassembled, moved, and rebuilt in 1976. The Plymouth Schoolhouse is symbolic in every way of our educational heritage. Originally built in 1874 in eastern Russell County, Kansas from hard post-rock limestone, it was one of approximately 60 such edifices spread across the county at the turn of the twentieth century. The schoolhouse has student desks of various sizes to accommodate students from grades one through eight who were taught by a single teacher of all eight grade levels. The schoolhouse has lasted more than a century and provides younger generations with a look into our rural educational history.

Figure 1

Plymouth schoolhouse located on the campus of Fort Hays State University

Note: Photo published with permission of Fort Hays State University (https://www.fhsu.edu/smei/plymouth-schoolhouse/)

Students in our Rural STEM Teaching seminar course visit the schoolhouse to contemplate what education must have been like a century ago. They examine the gradebook that was left from the classes taught there in 1922, listing the attendance and scores of seven students. They examine textbooks in mathematics, physical science, and biology that were used at the turn of the twentieth century. Students are asked to think about what education must have been like for these students who learned the three Rs in this building. Can they imagine students walking in the wintertime over the snow-covered Kansas prairie for a day of schooling and returning home at the end of the day to their farm chores that must be completed before supper time? They are also asked to think about what education will look like in rural Kansas communities in the future. What will rural Kansas look like 100 years from now?

Carr and Kefalas (2010) describe the undoing of rural America that has been taking place in recent decades in their book *Hollowing out the Middle: The Rural Brain Drain and What it Means for America*. More than 700 rural counties have lost 10% or more of their population since 1980. The young people from these areas that are moving away include the most capable students that head to universities with the excellent education they received in their hometown rural schools. The hollowing out is widespread and debilitating, and as the authors contend, ultimately detrimental not only to the region but to the nation. "What is happening in many small towns—the devastating loss of educated and talented young people, the aging of the population, and the erosion of the local economy—has repercussions far beyond their boundaries. Put simply, the health of the small towns that are dotted across the Heartland matters because, without them, the country couldn't function in the same way that a body cannot function without a heart" (Carr & Kefalas, 2010, p. vii).

Seminar students read and discuss *Teaching in Rural Places: Thriving in Classrooms, Schools and Communities* (Alanzo et al., 2021). As students read the book, their thinking is challenged about teaching and living in a rural community. They come to understand and reflect on many of the issues that rural students face such as isolation, limited access to resources, poverty, and teacher shortages. Additionally, they come to see rurality as an education inequity in which 8.9 million US students live and learn. Rural schools and communities have been systematically disadvantaged economically, culturally, and politically. Educating students in rural schools *is* a project of social justice that deserves as much attention as any other issue disadvantaged populations face (Azano et al., 2021). The book invites the readers to "engage in the important work of *remembering* what is strong about rural communities, *restoring* that which benefits rural people and places, *conserving* qualities of rural communities that should be protected, *changing* that which oppresses or divides us and *creating* new innovative ways to help rural communities thrive" (Greenwood, 2013, p. 99).

Those of us who choose to serve rural schools and communities as our calling in life have much important work to do. An important first step in reversing the downward spiral of the rural communities that we care about is to rethink education in small towns (Carr & Kefalas, 2009). Education opportunities must be equitable for all races, language learners, and socioeconomic groups and students must be well prepared to be successful in college should they choose to go. Perhaps most importantly, there must be a more equitable distribution of resources for those students that chose to stay in rural communities so they can compete in a post-industrial economy that is driven by STEM knowledge and skills. The authors in this issue describe their approaches and research that makes a difference for rural STEM education which will shape the future of STEM education into the next century.

STEM Teaching and Learning in Rural Communities: Exploring Challenges and Opportunities: Articles in this Issue

In this special issue of *Theory & Practice in Rural Education*, article submissions crossed a variety of topics, but three main themes emerged: (a) making STEM teaching relevant, (b) promising practices, and (c) professional development. The first three articles are under the theme of making STEM teaching and learning relevant in rural schools. The final four articles include information for professional development for rural STEM teachers. The final four articles provide promising and effective educational practices in rural schools STEM education. As editors of this issue, it is our privilege to provide a brief overview of each article in this special issue.

Research Forum

Integrating a Sustainability Education Model into STEM Courses at a Tribal College: Building Diverse Scientists via Science Identity Development

In this first study, Liliana Caughman (2022) explored the impacts of implementing a Sustainability Education pedagogy in science courses at a tribal college in order to understand student attitudes towards a science and sustainability curriculum. STEM education must be transformed to welcome and support the achievement of Indigenous scholars. Results indicate that students are receptive to this curriculum and that they have a positive experience in sustainability focused science courses. Tribal Colleges and Universities as well as other institutions of higher learning can use this work to better understand what leads to Indigenous student success in STEM and update pedagogies accordingly.

Co-designing a Rural Research Practice Partnership to Design and Support STEM Pathways for Rural Youth

The process in which local community members came together to support students through the Research Practice Partnership (RPP) is described in this third article. RPPs are long-term collaborations with researchers and practitioners. Srinjita Bhaduri, Quentin Biddy, Colin Hennessy Elliott, Jennifer Jacobs, Melissa Runnel, John Ristvey, Tamara Sumner, and Mimi Recker (2022) describe their findings of developing an RPP that focused on bringing communities together to co-design opportunities for underserved youth in rural communities through a local STEM ecosystem.

Integrating Computational Thinking in Rural Middle School Art Classes in Eastern North Carolina

In this article, Martin Reardon (2022) describes the integration of computational thinking into music and visual arts in three rural school districts who were part of a research practitioner partnership (RPP). Through the RPP, computational thinking was refined and adapted to the rural contexts in collaboration with the teachers. Additionally, an overview of the curricular activities for the visual arts is discussed as well as student perspectives on the concepts and approaches of computational thinking

Rural Secondary STEM Teachers' Understanding of the Engineering Design Process: Impacts of Participation in a Research Experiences for Teachers Program

In the next article, Teresa Shume, Bradley Bowen, Jewel Altimus, and Alan Kallmeyer (2022) explore STEM teacher professional development which is not equally available to educators in rural districts. The study investigates the impacts of a Research Experiences for Teachers (RET) program on rural mathematics, science, and technology education teachers. The STEM teachers engaged in a 6-week professional development experience focused on research and implementing the engineering design process. It demonstrated that an engineering-based RET program can increase rural teachers' commitment and readiness to incorporate the engineering design process into their regular classroom practices.

Rural Educational Leader Perceptions of Online Learning for Students with and Without Disabilities Before and During the COVID-19 Pandemic

The pandemic caused many challenges to the delivery of instruction for students. Todd Sundeen and Michelle Kalos (2022) describe the qualitative results of an online study of educational leaders' perceptions on the use of online instructional technologies before and during the COVID-19 pandemic. The article provides a unique portrait of that crucial moment for educators, students, and parents.

Building a Virtual STEM Professional Learning Network for Rural Teachers

The engagement of teachers in virtual and hybrid STEM professional learning opportunities is the subject of the article by Julie Thiele and Ollie Bogdon's (2022). The engagement of teachers resulted in three major themes of 1) increased collaborations, 2) equitable design of a professional development model that was successful at initiating a network for rural teachers to engage in STEM learning through investigations, collaborations within and between districts, and coaching activities access to resources and learning, and 3) increased content and pedagogical content knowledge. The project led to the design of a professional development model that was successful at initiating a network for rural teachers.

Virtual Summer Institutes as a Method of Rural Science Teacher Development

In this article, the team of Stephen L. Thompson, Rachelle Curcio, Amber Adgerson, Kristin E. Harbour, Legth Kate D'Amico, Hall S. Wes, George J. Roy, Melissa A. Baker, Jessie Guest, and Catherine Compton-Lilly from the University of South Carolina (Thompson et al., 2022) describe a virtual science summer institute they created as an initial component of an 18-month rural Teacher Residency program. The institute brought teacher candidates together with school-based teacher educators, university-based teacher educators, program faculty, and elementary students from the local community to take part in shared virtual teaching and learning experiences. The shared experiences occurred within authentic rural schooling contexts, provided teacher candidates with initial practice teaching opportunities, promoted the development of coaching and mentoring relationships, and allowed all stakeholders to develop common lexicon and ways of thinking about teaching.

Rural Teacher Attitudes and Engagement with Computing and Technology

The final article in this special issue on STEM teaching and learning in rural communities speaks to rural teacher attitudes toward, approaches to, and engagement with making and computational thinking during STEM professional development and co-teaching learning experiences. Melissa Mendenhall, Colby Tofel-Grehl, and David Feldon (2022) used a sequential case study-mixed method to explore and examined the ways in which teacher attitude shifted throughout professional learning and instructional practice. Three broad themes emerged in the project: anxiety, independent learner, and integration. The authors found that attitudes toward technology can be moderated.

Practice Forum

Making STEM Teaching and Learning Relevant in Rural Schools

STEMulating Interest with a Rural Place-Conscious Curriculum

In this first article, Elaine Westbrook (2022) focused on place-conscious designs that explored the increase in students' interests in STEM in grades 3-5. In this study, the effects of three informal instructional methods (hands-on, role model, and culminating projects) in a place-conscious curriculum on STEM interest were investigated. Results indicate that STEM interest increased through collaborative work, new knowledge, and action research.

All Kinds of Text: Investigating a Phenomenon Through Multimodal Media

Making STEM teaching relevant in practice is the focus of this article in the STEM teaching and learning in this rural communities special issue. As education candidates explore a real-world phenomenon through a multimodal text using the Next Generation Science Standards (NGSS) Science and Engineering Practices in order to obtain and evaluate information, candidates use the science and engineering practice of obtaining, evaluating, and communicating information to interact with a variety of information sources to help students investigate and make sense of a phenomenon of a growing, flowering, but non-fruiting tomatillo. Frederick Peinado Nelson (2022) discusses the approach of using multimodal texts that situates the learner as an investigator rather than in the traditional assignment mode.

A University-Community Partnership Model to Support Rural STEM Teaching and Student Engagement

Kathleen Kavanagh, Jan DeWaters, Seema Rivera, Melissa Carole Richards, Michael Ramsdell, and Ben Galluzzo (2022) describe a partnership between a small, private STEM university and rural schools in upstate New York which could be a model for other rural-focused universities as they strive to enhance STEM teaching and learning. University and community stakeholders were actively engaged in STEM enrichment and professional development through summer camps, after-school activities, student mentors, and curriculum designed to prepare teachers to work in high-need school districts.

Final Thoughts

We hope you enjoy this special issue of Theory and Practice in Rural Education. Of upmost importance to us is STEM teaching and learning in rural communities. As Azano et al. (2020) expressed:

> We invite teachers to engage in the important work of remembering what is strong about rural communities, restoring that which benefits rural people and place, conserving qualities of rural communities that should be protected, changing that which oppresses or divides us, and creating innovative ways to help rural communities thrive. (p. xi)

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About the Authors

Janet K. Stramel, PhD, is a Professor and Edna Shutts Williams Endowed Chair of mathematics and elementary education in the Department of Teacher Education at Fort Hays State University. She teaches mathematics methods courses for early childhood and elementary pre-service teachers. Janet has published articles, book chapters, a book, and has presented at numerous professional conferences at the international, national, regional, and state levels. jkstramel@fhsu.edu

Earl Legleiter is the director of the Science and Math Education Institute at Fort Hays State University where he teaches a Rural STEM Education seminar. He earned his MS in Advanced Educational Programs – Science from Fort Hays State University in 2016. He has taught various science courses for over 20 years in rural high schools, some of those years as the only member of the science department. He also provides NGSS and Modeling Instruction professional development for in-service teachers nation-wide. eflegleiter@fhsu.edu

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Integrating a Sustainability Education Model into STEM Courses at a Tribal College: Building Diverse Scientists via Science Identity Development

Liliana Caughman, *Arizona State University*

Indigenous scholars have been historically excluded from Science, Technology, Engineering, and Math (STEM) and are currently underrepresented in STEM degree programs and jobs. Having a population with STEM skills is crucial for rural sovereign Native American communities to manage their natural resources, infrastructures, and technologies. Thus, STEM education must be transformed to welcome and support the achievement of Indigenous scholars. This research explores the impacts of implementing a Sustainability Education (SE) pedagogy in science courses at a Tribal college that serves rural and semirural Native American students. Using pre- and post-surveys as well as phenomenographic interviews this work aims to understand student attitudes towards the combined science and sustainability curriculum. Results indicate that students are receptive to this curriculum and that they have a positive experience in sustainability focused science courses. Additionally, the SE science courses positively impacted students' science identities, which has been shown to contribute to persistence in science. Tribal Colleges and Universities and other institutions of higher learning can use this work to better understand what leads to Indigenous student success in STEM and update pedagogies accordingly.

***Keywords*: Sustainability Education, Tribal Colleges and Universities, STEM Education**

Native Americans play an enormous role in natural resource management (Jostad et al., 1996). Across the country, Tribes manage large swaths of land in rural areas and work to sustainably maintain everything from salmon populations and old growth forests to estuaries, prairies, freshwater resources, and more (Charnley et al., 2007). Additionally, sovereign nations are responsible for their own community development and infrastructure, including wastewater treatment, emergency preparedness, and electrical grids, among other things. Managing every one of these endeavors requires serious science skills and Tribes need their own people to fill science-focused positions and pursue related careers within tribal governments (Whyte, 2013). Currently, there is a shortage of scientifically trained and educated tribal members to fill these positions and often Tribes must hire outsiders for support. To combat this trend, many Tribes are making higher education a priority (Tinant et al., 2014). They see the benefit of having a scientifically literate community and believe it can strengthen both current and future generations, especially in a rapidly changing world.

Tribal Colleges and Universities (TCUs) primarily serve Native American or Indigenous students and are often located on sovereign tribal land, typically in rural or semirural areas.

Unfortunately, these students exemplify a group that is one of the most underrepresented in the sciences. Students, especially students who have intersectional characteristics, like those who identify as a person of color, female, poor, and disabled -- simultaneously, are some of the most likely to struggle in STEM classes and avoid STEM careers (NSF, 2015). However, these students have limitless potential and deserve the chance to positively engage in the sciences and build their confidence. When successful STEM courses are implemented, more students seek out STEM classes, build their analytical skills, and open their minds to pursing science related jobs (Maltese & Tai, 2011).

Many Tribal students enter class with deep admiration for the natural world and their cultural heritage but fail to see the connection between those values and the material they learn in science classes (Oatman, 2015). Hence, by implementing an interdisciplinary Sustainability Education (SE) model that includes these topics within standard Science, Technology, Engineering, and Math (STEM) courses at the college level there is an opportunity to tap into the students' interests and allow them to better engage with science material.

To understand if integrating the SE model into STEM courses at TCUs does in fact produce these outcomes, this research investigates the following question: What are TCU students' perspectives on learning science through topics in sustainability? This research aims to decipher this inquiry by exploring the students' experiences in an integrated science and sustainability course, investigating how they conceptualize both science and sustainability, and discovering how they see their ability to participate in both disciplines. This is achieved by: 1) surveying students on their attitudes towards science and the environment before and after their participation in an integrated science and sustainability course, and 2) conducting in-depth interviews with students at the completion of their course.

The results of this study show that the TCU students are receptive to this type of hybrid science and sustainability curriculum, and therefore TCUs and other institutions of higher learning the serve Indigenous scholars can adopt this pedagogy. In doing so, there is the opportunity to propel more Indigenous learners to succeed in science and fill vital science and natural resources positions on their land and beyond.

Additionally, shifting towards a sustainability curriculum in science may not only benefits Native American students, but others who have been excluded like women, people of color, people with disabilities, and those from historically excluded backgrounds. Many of the pedagogical approaches prescribed by the SE model have been shown to create an advantageous learning environment for an extensive spectrum of students. Therefore, the SE approach should be applied and evaluated in other institutions of higher learning.

This article explores the complex nature of creating inclusive and equitable STEM education for rural and semirural TCU students, the mechanics of the SE model, and the specific needs of Indigenous learners in science. Analysis of student surveys and interviews are presented and findings on science identity traits and student opinions on the SE curriculum in STEM classes are thoroughly reported, offering insights into how results can be applied in the future.

Background

It is no accident that Native Americans, and particularly Indigenous women, are significantly underrepresented in the sciences. The systematic European colonization, Christianization, and subjugation of American Indigenous people have led to the absence of Native Americans in science today. By means of attacking cultural identity, and enforcing a westernized society and educational system, Native Americans were strategically disempowered, and their communities continue to feel the effects of this trauma (Guerro, 2003; Tsosie 2010). Colonial history and current manifestations must be considered when tackling the paucity of Native Americans within the scientific community.

Indigenous groups have faced brutal treatment through colonization and implementation of rules that marginalize their culture and force a dominant, usually Anglo, society upon them. The US driven removal of Indian children who were sent to boarding schools caused lasting trauma and these painful scholastic experiences continue to haunt; it is no wonder that a distrust of western education has formed in indigenous communities (Smith, 2021; Tsosie, 2010). Additionally, there has been ongoing hostility towards and often an outright dismissal of Indigenous traditional knowledge in the western science classroom (Smith, 2021). When it comes to increasing participation of Native Americans in science, this is especially relevant, however, often ignored. Typically, modern problems like, rural location, small population, poverty, or learning differences are used as the basis for understanding the current dearth of Native Americans in STEM. However, negating history does not allow the current problems to be fully understood, and therefore solved. We must acknowledge how detrimental colonization and westernization are to the Indigenous population regarding their education, and actively work for justice and reform.

Sustainability Education (SE)

Introducing sustainability topics and classes into conventional school settings is one strategy being considered to move status quo educational practices in a new direction. Since the early 1990s there has been growing interest in developing sustainability focused pedagogies for use in higher education (Tilbury, 1995). This type of SE can be applied in a plethora of ways and take many forms. The model is flexible and adaptable for use in a variety of classes and circumstances and shifts depending on the goals of the educator using it. This keeps course topics and practices relevant and malleable, which is one of the strengths of implementing SE in a modern classroom. For the purposes of this research, SE will be understood as an interdisciplinary educational model, which appropriately prepares students for an uncertain future in the context of global climate change. Although there is no official consensus among sustainability educators, some version of this definition generally appears in applied SE (O'Byrne et al., 2015; Wals, 2014; Wright & Horst, 2013).

The model of SE used in this study consists of: 1) development of Higher Order Cognitive Skills (HOCS) by means of problem solving and critical thinking (Zoller, 2015); 2) integrated, interdisciplinary classes combining topics of science, technology, environment, society, policy, sustainability, etc. (Coops et al., 2015; Ward et al., 2016); 3) experiential and applied learning opportunities including the use of learning communities, community based research, mentoring, and dissemination (McPherson et al., 2016; Wilson & Pretorius, 2017); and 4) a strong interwoven focus on the environment and social justice (Drolet et al., 2015; Wiek et al., 2014).

Science Identity

The development of a science identity, the psychological process of one being inspired by STEM to the point of personal relevance, ownership, and integration into the sense of self is one of the leading factors of success in STEM (Brickhouse et al., 2000). Science identity describes how students are engaging in science and how this is related to how they seem themselves rather than simply what science facts they know. Using a science identity-based framework to understand historically excluded groups (HEG) persistence in science has proven to be a robust and trusted method (Hazari et al., 2010).

Since science identity has come to the forefront of engaging HEGs in STEM, researchers have turned to studying curriculum, pedagogies, and programs that may positively impact student's science identity. This research shows that even minor changes in curriculum (like exposing students to the academic work and personal background of diverse researchers) or creative tweaks to classroom assignments can have large and lasting positive impacts on students, their science identity, and success in STEM (Schinske et al., 2016).

Native American Teaching and Learning

While many studies focus on HEGs in the sciences, fewer focus specifically on the needs of Native American students. Often, studies will group Native learners into the demographic category of "other" which fails to highlight their unique experiences as science students. However, many of the strategies that are emphasized for a variety or HEG students are applicable for Native American students. For instance, the importance of mentors for Native American learners (Maughan et al., 2001) and the significant role of personal identity within the science classroom (Oatman, 2015). While each of these components contributes to a positive learning experience for Native students, two of the most important aspects necessary for student success are place-based learning and culturally sustaining pedagogy (Kowalczak, 2013; McCarty et al., 2014; Oatman, 2015; Riggs 2005; Roehrig et al., 2012; Semken, 2005: Sleeter 2012).

Best practices in science education for Native American students includes the need for place-based curricula. Science classes should offer material that is experiential, connects students to their homeland, and gets students outside studying familiar environments from a scientific lens (Riggs, 2005). This pedagogical approach aligns with the importance of experiential learning opportunities, socially relevant material, and community focused practices, shown to be pertinent for the success of all HEG groups within the sciences. The biggest difference between what other HEGs require and the specific needs for Native American learners, is the extent to which these practices are important. Connection to place and community runs deep particularly on traditional lands which Tribes have lived on since time immemorial. Additionally, a place-based and culturally connected curriculum can have a positive influence on students' science identity (Kowalcak, 2013). As mentioned in previous sections, the growth of a positive science identity is crucial for one's desire and motivation to continue within in the sciences.

Indeed, when a culturally sustaining pedagogy (CSP) is properly implemented in the classroom it can motivate students by valuing both their identity and cultural expression (Oatman, 2015). Tribal sovereignty, and the recognition that Tribes have the right to full self-governance, should be at the core of CSP teachings (McCarty et al., 2014; Oatman, 2015). Material taught in class should be cognizant of colonizing influences and should also make space for the reclamation of Indigenous language and culture (McCarty et al., 2014). Often this means that the course curriculum should engage in community-based research and educational activities, while also offering students the opportunity to critique social issues and institutions surrounding race and inequity (McCarty et al., 2014; Oatman, 2015).

Despite the best intentions of educators, CSP can be challenging to include in the classroom, and it has generated some criticism when improperly applied (Nykiel-Herbert, 2010; Sleeter, 2012). Research by Sleeter (2012) points to three main condemnations that feature an incorrect interpretation and application of CSP: simplification, trivialization, and substitution of cultural relevancy. For example, to simplify could mean to merely "celebrate" culture in the classroom, which does not fully constitute culturally relevancy and therefore does not foster student success (Nykiel-Herbert, 2010; Sleeter, 2012). Trivialization could indicate an occasional culturally related activity but no further integration, and substitution avoids discussing issues surround racism and oppression in hopes that talking about tolerance is enough (Sleeter, 2012). Instead, cultural relevancy must be fully engrained into the curriculum, it should be utilized as a means for learning, and it must enable students to use their own lives to deepen their scholarship (NykielHerbert, 2010; Sleeter, 2012). In general, it is important for educators not to diminish the culturally focused parts of the curriculum; they must unequivocally and confidently incorporate interdisciplinary topics regarding tradition, community, and the reality of colonialism in their courses so that their Indigenous students can triumph.

Integrating Sustainability Education and STEM for Native Scholar Success

There must be a paradigm shift within science education to better make space for HEG learners, and specifically Native Americans. Dull, theoretical, individualistic and sterile STEM courses alienate a diverse set of students and appeal primarily to the status quo scientists: white and Asian men. In order to become more inclusive, science curricula must make a transition towards place-based activities, experiential learning opportunities, culturally sustaining pedagogies, community-oriented practices, and generally more socially relevant material.

Thinking back to the description of SE it appears that there is overlap between what the SE model prescribes for science curriculum and what Indigenous and other HEG students require to succeed in STEM. In particular, implementing SE in STEM would be a paradigm shift in higher education; it would redefine what it means to study science. This offers a chance to redefine the traits of scientists and could give students new opportunities to imagine themselves as scientists, thus supporting the development of their science identity.

Further, the combined SE in STEM model puts experiential and community-based learning at its core. There is a strong focus on local research experiences for students and learning community activities are made a priority in the classroom. This directly connects to research that has shown how important community involvement and hands-on learning opportunities are to retain Native Americans and other HEGs in STEM. It has been well documented that HEG students respond better to STEM fields in which the effects of their research can benefit society. Additionally, it has been shown how crucial it is for Native American students to have culturally sustaining classroom material that connects to both tradition and institutional inequities. Yet again, the SE model calls for these interdisciplinary issues to be included within standard science curriculum. Specifically, the model prepares students to face the interdisciplinary issues of the Anthropocene and urges them to find creative solutions to problems like global climate change and local environmental injustice. This focus on a big, interconnected picture could very well inspire students by allowing them to emotionally connect with their work and connect it with their lives.

The connections between the SE model and the needs of Native Americans and other HEGs in STEM cannot be overlooked; there is strong potential here to move science into a new direction that is more appropriately structured for a diverse set of students to thrive. Currently, there is no research exploring the potential of the SE pedagogy to engage HEGs or Native American students in science. This research aims to uncover if indeed this SE model creates an advantageous learning environment for Native Americans within STEM by means of implementing the pedagogy and surveying and interviewing the student participants regarding their experience.

Methodology

The goal of this research is to understand if implementing the sustainability model within STEM classes is advantageous for rural and semirural TCU students. This study uses a purposive selection of TCU students were surveyed and interviewed regarding their experience participating in a science class that incorporated the SE curriculum. The survey results were analyzed quantitatively to describe students' attitudes towards science and sustainability immediately before and after participation in the course, as well as to describe the demographics of the study group. The interviews were transcribed and then coded using a phenomenographic qualitative analysis technique, rooted in the theory of science identity.

Rural Reservation Study Site

This study took place at a TCU serving Indigenous students in the Pacific Northwest. The location of the research is a reservation-based branch of the larger TCU, which has a main campus and smaller site campuses distributed across rural and semirural Indian reservations. Specially, this research took place at a small site on a rural reservation with a population of approximately 600 people, and college enrollment of about 50 people. The local economy is based on natural resources (primarily fisheries and forestry) and the casino.

Science and Sustainability Courses

The students who participated in this study took either an "Introduction to Biology" or "Introduction to Geology" science course that incorporated the SE curriculum model. These quarter-long courses are at the freshman undergraduate level. Class sizes at this college are small, there were six students enrolled in Biology and eight enrolled in Geology.

For both courses, each standard life or earth science module was accompanied with a topic and activity that highlighted a connected environmental, social, cultural, or economic sustainability issue. This gave meaning to the material and drew students into the courses in a tangible way, while also increasing their sustainability literacy.

Student Participants

Each student enrolled in Biology and Geology was invited to participate in this study, but it was not a required part of the course. In the end, nine students participated in both the pre and post surveys (five from biology and four from geology) and 10 students participated in interviews (six from biology and four from geology). The following table describes the demographics of the students:

Table 1

Demographics of Student Participants

Characteristic	Category	Number of Participants (n)	Percent (%)
Age			
	Under 18	0	0%
	18-24	2	22%
	25-34	3	33%
	35-50	3	33%
	Over 50	1	11%
Race/Ethnicity			
	Native American or Indigenous	9	100%
	Caucasian (mixed)	2	22%
Year in College			
	1 (freshman)	5	56%
	2 (sophomore)	3	33%
	3 (junior)	1	11%
Number of previous college science classes			
	0	4	44%
	1 or 2	4	44%
	3+	1	11%

Table 1 shows the self-reported demographics of the students who took part in this study. All students identified as Native American or Indigenous. Most students were early in their college careers and had taken two or fewer science courses. Student ages varied widely.

Surveys

The students who were involved in this study were surveyed immediately before and after participation in their science course. The nine students who chose to participate in this portion of the study took the pre-class survey on the first day of class before instruction began. They then took the post-class survey on the last day of class, directly after instruction concluded. The survey instrument consists of 34 questions that were taken from scales developed by the Cornell Citizen Science Group.

Survey data was analyzed using a pre-post method of comparison. Four areas of the survey were analyzed 1) self-efficacy for learning and doing science, 2) self-efficacy for environmental action, 3) nature relatedness, and 4) interest in science. Taken together, the results from these surveys provide a representation of the students' baseline feelings towards science and the environment from both a personal and academic stance. The data were analyzed and interpreted using the methods as outlined on the survey tool 37 scoring instruction guidelines (see Appendix 1). This data is used descriptively as the sample size for this study is quite small.

Interviews

Students who were involved in the study were interviewed regarding their experience in the science course within one week of completing the class. There were 10 students interviewed overall and each interview session lasted approximately 30 minutes. The interviews were audio recorded and then each recording was manually transcribed.

The goals of the interviews were to: 1) explore students' prior and current perceptions of science and sustainability, 2) explore students' views toward the science lessons contextualized in issues of sustainability, 3) describe the students' views of experiential learning as it relates to the scientific lessons, and 4) describe students' perceptions of their ability to take part in scientific and/or sustainable actions. In general, the aim was to understand at a deep level the individual learning experiences of individual students.

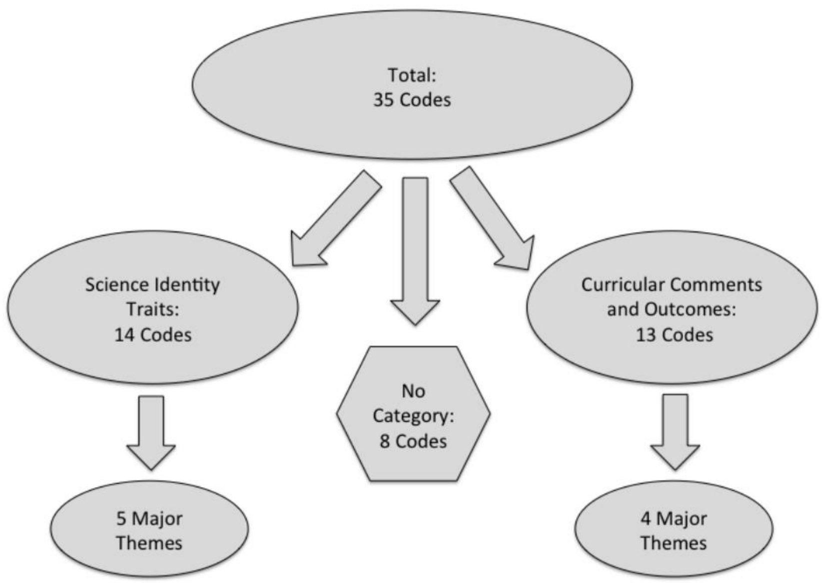
The qualitative data obtained via the in-depth interviews were analyzed following a phenomenography method, combined with the theoretical basis of science identity. The sample size of 10 participants meets the requirements for qualitative phenomenology research, which suggests a sample size of 5-25 participants (Creswell and Poth, 2016). When conducting phenomenographic educational research, the aim is to explain variation in student learning experiences (Waters, 2016). Therefore, the interviews were as non-directive as possible and the students could take the conversation in whichever way worked best for them and their communication style.

In analyzing the data, the focus was on a deep understanding of the meaning behind the descriptions given by the students. In phenomenographic research such as this, themes are essential aspects "without which the experience would not have been the same" (Waters, 2016). The themes were discovered through a thoughtful engagement with the student interviews and multiple, careful readings of the student responses.

Through this process 35 codes were created that captured the essence of the students' experiences and perceptions of learning science through the context of the sustainability curriculum. The coding process focused on understanding the student's words in the context of their life experience, classroom experience, and overarching science identity. From the original 35 codes, similar codes were grouped together. Two major grouping were formed: 1) Science Identity Traits and 2) Curricular Comments and Outcomes; eight codes emerged that did not fit into any predominant thematic category. After the codes were placed into the main two groups, subgroups were formed by again placing similar codes together. This process revealed five major Science Identity Trait group themes and four major Curricular Comments and Outcomes group themes (see Figure 1).

Figure 1

Breakdown of codes and theme categorization. From a total of 35 major codes two large groups were formed. Each of those large groups contains major themes that are further described in the results.



The overall groupings and subthemes were then analyzed in the context of previous research in the fields of science identity and sustainability pedagogy in order to reveal how student identities overlap and interact with the science and sustainability curriculum. Additionally, the codes were analyzed quantitatively. Code counts and co-occurrence tables were utilized to investigate unique and informative overlaps between codes that demonstrate students' learning experiences and highlight their science identities. Finally, a science identity "thumbprint" was developed for each student to visually and quantitatively express the differences and similarities in science identity and how that connects to STEM and sustainability learning.

Results

Two large motifs arose upon analyzing the interview data: 1) each student exhibited a unique combination of overlapping science identity traits and 2) students expressed shared attitudes and feelings towards the science and sustainability curriculum. Survey data supports the findings from the interviews and shows that students experienced attitudinal changes over the extent of their participation in the science and sustainability courses.

Survey Data

There were nine students surveyed immediately before and after participation in the science and sustainability course. The surveys aimed to measure science and sustainability literacy by means of examining interest in science, nature relatedness, self-efficacy for the environment, and self-efficacy for science. Students exhibited a positive shift in all four categories of the survey after participation in the course, including a 14% increase in science and sustainability literacy (See Table 2).

Table 2

Survey Results

Survey Results					
	Interest in Science	**Nature Relatedness**	**Self-efficacy for Environment**	**Self-efficacy for Science**	**Overall**
Pre-survey score	3.18	3.80	3.54	2.86	3.30
Post-survey score	3.65	4.20	4.07	3.42	3.79
Change	**0.47**	**0.41**	**0.53**	**0.56**	**0.49**
(% Increase)	(15%)	(11%)	(15%)	(19%)	(15%)

Students used a Likert scale from 1 to 5 to self-assess their feelings towards each category. Selecting 4's and higher indicate stronger science and sustainability literacy. This summary in Table 2 shows that students score higher in each category after participation in the course.

The surveys also showed that students who started with the lowest scores in each category were the students who showed the most growth by the completion of the course. For example, four out of nine students scored low on "self-efficacy for science" at the beginning of the course with an average score of only 1.8 on the scale. By the end, those same students scored an average of 3.9 in that category, a 68% increase. Students who scored higher at the beginning of the class showed little to no change. This can still be considered as a positive outcome since the students began with strong science and sustainability literacy and maintained this level throughout the course. Although, it may also indicate that this curriculum is a more powerful educational tool for beginning students, early in their science and sustainability careers.

Interview Data

The interview data was analyzed under two large overarching categories, which materialized during the coding process. The first category is "science identity" or how the students integrated the class material into their personal lives and sense of self. The second category is "curricular comments and outcomes" wherein students describe their classroom experience and discuss their attitudes and skills regarding science and sustainability. The findings from this analysis illustrate how the SE curriculum impacts individual students on a deeply personal level (science identity) as well as on a tangible level (curriculum comments and outcomes). Based on the results of this study, it seems that SE curriculum was beneficial for these TCU students.

Science Identity Traits

Under the category of science identity five major themes arose, each one correlating to a style of science identity. These themes can be used to describe the type of scientist with whom each individual identifies (either fully or partially). The science identity groups are called: 1) The Personal Scientist, 2) The Career Scientist, 3) The Family Scientist, 4) The Active Scientist, and 5) The Cultural Scientist. Each science identity group is described and analyzed in depth below.

Interpreting the Science Identities

Each student is unique and demonstrated an individual mix of science identity traits. To highlight these differences, Figure 2 shows a Science Identity "Thumbprint" for each student. To create the thumbprint the total number of identity traits demonstrated by each student was counted. Then, the number of identity traits in each category was counted so that a percentage corresponding to each identity group 45 could be developed. Every student has a science identity totaling 100%, which is divided up among one or more of the science identity categories.

Figure 2

Science Identity "Thumbprints" Chart

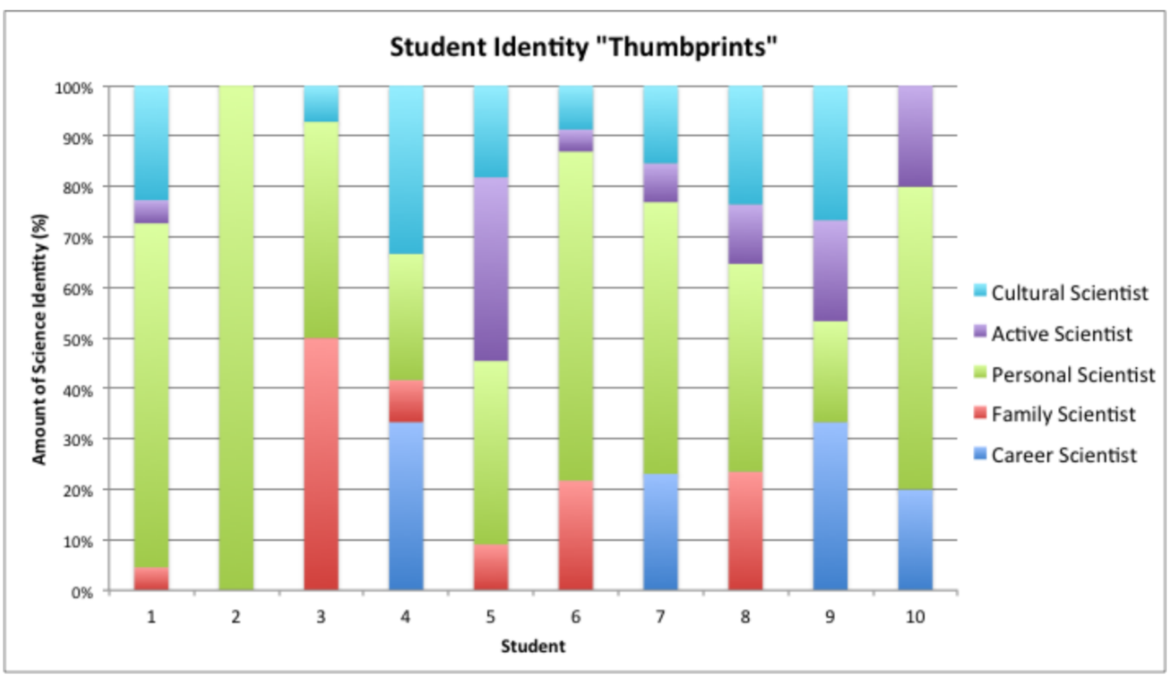


Figure 2 graph shows the student identity "Thumbprints" generated from an analysis of the interview data. Each student has a science identity totaling to 100%, broken down into the percentage of trains from each science identity category they exhibited.

The Personal Scientist

The Personal Scientist identity belongs to those who are interested in benefiting their own personal life through science and sustainability. Examples include gardening, making healthy choices, becoming self-sufficient, personally surviving climate change, and generally bettering themselves and their local environment. The Personal Scientist identity was the most popular of all identities within the group of participants. Every participant demonstrated at least some Personal Scientist identity traits. For seven participants this was the strongest aspect of their identity. One student demonstrated only Personal Scientist traits. Others showed a very high number of these traits as compared to the other areas of their science identity.

Many respondents also mentioned that learning about science and sustainability could help them personally survive and thrive. They stated that by understanding these topics and living by them they could become more self-reliant. Many respondents also mentioned that learning about science and sustainability could help them personally survive and thrive. They stated that by understanding these topics and living by them they could become more self-reliant. These findings and associated quotes are shown in Table 3.

Table 3

Personal Scientist traits, interests, and supporting quotes.

Science Identity Trait & Area of Interest	Supporting Quote
Food & Health	"We can do so much stuff from food. Food was one, that's a big thing, especially in native country where diabetes is a high killer, high cholesterol, high sugars, all that stuff. Like I said the one [science thing] I'd want to get into is the gardening and stuff."
Self-reliance	"… Science has to do with living. I mean, what happens if we don't have the Internet or we don't have no more oil, what if everything just shuts down? It's good to know about your environment and how to make things work or adapt."
Personal Choice	"Oh yeah, the more I get more knowledgeable about science and our environment, the more I make different changes. Don't idle my car, you know, just little things, there's some things like I have bad habits. Like I use a lot of plastic grocery bags. I don't bring them back! And I get so mad at myself!"

The Career Scientist

The Career Scientist identity belongs to students who are either pursuing a science degree or career, or who want to utilize science within their career. Examples include farming, resource management, or businesses that utilizes modern science and technology.

There were four participants who demonstrated the traits of a Career Scientist identity. One participant is pursuing a science major and plans to be the head of Fish and Wildlife at their Tribe in the future. One participant is a science entrepreneur who is interested in incorporating science, sustainability, and engineering into a start-up company. One participant has worked on a farm that practices sustainable agriculture and might want to pursue this again in the future.

The final participant is highly interested in a science career in fisheries biology connected to their Tribe and has also thought about teaching science.

Two Career Scientists stated that they already felt confident in their science skills before taking the course. These students felt the curriculum used was highly beneficial to their peers who might just be experiencing college level science for the first time. This sentiment seems to be validated by the aforementioned survey results in which students who scored lower on self-efficacy for science showed the most improvement by the end of the course. One Career Scientist student gained a noticeably stronger interest in pursuing science from taking the course. The student mentioned using the class as a way to gauge if a science career really was in their future and found that many topics in the class stimulated their interests and motivation. All of the Career Scientists were fairly confident in their ability to participate in science by the end of the course.

Table 4

Career Scientist traits, interests, and supporting quotes.

Science Identity Trait & Area of Interest	Supporting Quote
Motivation	"I really think this is like a recommended class for beginning students. Especially just to get them, like I said, a little wet into the science field and maybe it might plant some thoughts into people. I mean; I would probably have been in my degree a lot sooner if maybe I had taken this class. Because you don't know what's out there in the science fields, it's so open and confusing almost. And I think this [course] helped."
Interest	"The exposure to science through a sustainable lens can actually create scientists because there are a lot of people that don't really understand maybe what scientists do so they take a class that's required of them, they don't really have a major yet and they find out that they absolutely love science and they love, love the sustainability aspect of it and then three years later they're sustainable scientists!"
Confidence	"I'm kind of hoping like with these classes, it would, I'd get more of a solid answer, a solid yes or no, like is [science] something that I could do? Is this something, I mean, I know I'd like to do it but it's like, can I really do it? I think the answer is yes."

The Family Scientist

The Family Scientist identity belongs to students who care about science and sustainability for their family's sake or for the sake of future generations. Examples include doing experiments at home with family or children, wanting to have scientific experiences with family members, and passing on science and sustainability interest and skills to the next generation.

There were six participants who showed traits of the Family Scientist identity. Students spoke about gardening, fishing, and hunting with uncles and grandparents as children, and related this to learning topics that connected to their upbringing and family history. Some spoke about completing science activities with family members on a regular basis and enjoyed doing experiments in class that could also be completed at home. Some mentioned teaching their children how to live more sustainably, by means of understanding the science-based consequences. Several spoke about sustainability as connected to “7 generations” specifically focusing on children. Many were interested in understanding science and sustainability topics to better care for the health and wellbeing of their children, either in general, or in the wake of environmental dangers and climate change. Finally, a few specifically spoke about children in their lives who are interested in science, and whom the participants hoped to intellectually stimulate and educate. These findings and associated quotes are shown in Table 5

Table 5

Family Scientist traits, interests, and supporting quotes.

Science Identity Trait & Area of Interest	Supporting Quote
Family History	“I think I've always been more of an outdoor person, I remember my uncle on my mom's side he had a whole garden, big outdoor garden, and a greenhouse and when we'd go visit him, you know, he'd say, you guys better go out there and get your veggies and… I was looking at my mom she was looking, it was always cool to go get your own food… out in the garden and pick it and clean it. So that's always kind of been there and plus fishing, hunting, just always learned that you take care of [the environment].”
Family Activities	“… It's just good to know. Well, cause I'm hoping, because my sister got stuff to grow. I'm thinking we're going to do that. Try to start planting our own stuff. But the filter project it was just fun. It was just fun doing the data. I just liked that one. Just the mixing everything. It just felt like something me and my niece would do.”
Lifestyle	“You know, learning if there was a compost site near me. Teaching my son how to recycle. We're actually going through that phase right now, where he's going through the house and if there's cardboard or papers that need to be recycled, I send him to the recycling bin almost every other day.”
7 Generations	“I feel like if we can remember that it all comes back to us that can provide the motivation as to why we need to support the other aspects of things. If we remember that, you know, 7 steps down the line or 7 generations down the line, that could affect something regarding us or our children, which you could say are us as well, then you're more motivated to try and keep that process of a circle going but in a positive way, not in a negative way.”
Health & Wellbeing	“You know, for my son that has asthma. Or you know learning what fresh air is. Learning what clear water means. Learning the different things in a river. Like you know, the fungi, or what do you call those? The moss and how they develop and we know they're not bad for us, but they are contributing to our air. I guess because if you do have a kid who does have asthma, or eczema or allergies, those all tie in to one, so you know just learning what's good for him and what's not.”
Education	“[My son] loves clams. You know learning how to, the sea life, his uncles dive so he gets to hear that my brothers and them actually want to sit down and talk. They talk about that stuff and to him that's science. The whole [starfish dissection lab] was science to him. You know, he wanted to learn more, why was it, why are they like this, why are they like that? Why did your teacher say this? So it was learning about that, you know, out of our way, outside of class”

The Active Scientist

The Active Scientist identity belongs to students who want to use science to better understand social and environmental injustices and who care about activism and societal change. Examples include researching and being involved in the Standing Rock protests, exploring environmental injustices, and using science to find solutions and gain understanding of politics.

There were seven participants who expressed Active Scientist traits. Only one participant had the Active Scientist as (tied) for their strongest identity group. The other six participants experienced a low, but not negligible, level of Active Scientist traits.

Table 6

Active Scientist traits, interests, and supporting quotes.

Science Identity Trait & Area of Interest	Supporting Quote
Political Activism	"We were in Standing Rock because they were trying to build a pipeline... and the reason why there's such a high demand for oil is because of our cars! We all drive cars. And there's got to be another way of doing this without having to use oil… How are we going to get places without oil? And that's what I want to find out, I want to research. I want to learn more."
Resisting Colonialism	"…but I always would wonder if the army base pollutes our river. I would like to study it. The thing though would be like if they were dumping in our river and we didn't know about it, it would be quite the fight to get them to stop because it's the government against our little Tribe, so... It would be, I'd probably get pretty fired up about it."
Anti-capitalism	"… But since the power company couldn't control who gets power because if someone doesn't pay the bill you can't just shut of that carrier wave, because if you shut off that one carrier wave it shuts off the entire neighborhood and city so sustainable energy won't come around until we get rid of currency."
Society & Environment	"Well, each of those aspects are equally important if you're going to consider a giant social aspect of groups, grouping of people... but personally I think the most important would be the environmental sustainability because everything else pretty much depends on the environment working. If you don't have an environment your social structure collapse. Your social structures develop within an environment. We all come into the environment, the environment is here before us."

Political activism including protesting and forms of direct action were mentioned several times by participants. Participants focused on the recent Standing Rock and No Dakota Access Pipeline protests and potential future threats that they would likely fight against. The students often connected these topics directly to the need for science and research. The students seemed to be inspired to learn more science to better understand these issues, find alternatives, and fight for their rights. Participants in this group lamented the "American way of life" and understood their gains in science and sustainability as acts of resistance against these norms. Additionally, anti-capitalist sentiments were expressed by participants; again, the fight for both science and sustainability resonated with their motivation against pure profit. Lastly, some focused on the societal nature of environmental problems and scientific progress. These findings and associated quotes are shown in Table 6.

The Cultural Scientist

The Cultural Scientist identity belongs to those who understand the importance of science and sustainability in terms of Tribal sovereignty and cultural sustainability. Examples include connecting science and environmental sustainability to cultural sustainability, finding science important for traditional reasons, wanting to conserve indigenous culture, land, and animals, and wanting to use science and sustainability to benefit Tribes.

There were eight participants who exhibited the traits of Cultural Scientists. This identity was (tied) for the strongest identity in one individual, was relatively strong for three individuals, and was low for four individuals.

Table 7

Cultural Scientist traits, interests, and supporting quotes.

Science Identity Trait & Area of Interest	Supporting Quote
Sustaining Culture	“They brought the canoe journey back in 2005 and we're showing our people that we can still do this. That the ancestors are not the only 60 ones that are strong, that we can do this too. So I think that if we had to reverse [our modern lifestyles] in order to save our world then that's something we have to look into.”
Indigenous Heritage & Community	“It seems like more of the non-Tribal don't understand what I'm saying when I say I want to learn everything holistically, because I need to. As a Tribal member I have to go back into my community and know everything.”
Cultural Connection	“Yeah, to, to us [the plants are sacred]. From our family back home. So, just respecting plants and animals. You know, there's always a story and [my son] loves hearing stories. So just understanding how, how big animals play a role in our tradition, our every, almost everyday life.”

The idea of sustaining indigenous culture was mentioned by several participants. These students specifically noticed the connection between learning the necessary science, sustaining the environment, and keeping their culture alive. All of the students who showed Cultural Scientist identity traits connected their thoughts to their Indigenous heritage, Tribal community, or philosophy. In general, this group tied culture to their experiences in science and sustainability and saw science and sustainability as innately connected to who they are as Native people. Major themes included thinking of sustainability in the “7 generations” context and maintaining salmon populations. However, there were a wide variety of cultural connections brought forward by the participants that are best displayed as quotes to highlight their uniqueness. These findings and associated quotes are shown in Table 7.

Curricular Outcomes and Comments

Under the second major category "Curricular Outcomes and Comments" four major themes arose: 1) STEM Trauma & Recovery, 2) Science & Sustainability Connection, 3) Science Skills, and 4) Pedagogy Positives. Each of these themes emerged as students reflected on their experience in the course, and their thoughts, attitudes, and feelings towards science and sustainability, as well as the curriculum. Each of the themes is described in more details below:

STEM Trauma & Recovery

All ten interviewees mentioned either STEM Trauma or Recovery at least once during their interview. There were 17 incidences of past STEM trauma that were discussed. However, increased interest in science and sustainability was mentioned 18 times and a gain in confidence was noted 23 times.

Table 8

STEM trauma and recovery categories and supporting quotes.

STEM Trauma	Supporting Quotations
Science Weakness & Inadequacy	"On the first day of this class I was like 'I don't know anything about science, what am I taking a science class for?' ""
	Yeah, I'm not a really big science person so, when it comes to science I kind of grit my teeth because I don't like it... I can get excited about it, but then I realize what I am excited about is something I don't understand."
STEM Trauma	"Well, it was in high school many many moons ago. We had to write about careers, pick three of them. I just kind of put fish hatchery as one of my careers. And I kind of remember my teacher being like 'yeah right, you're not going to go that far', that kind of attitude. And I didn't blame her because I was a high school drop out, you know I wasn't very studious at that time."
Improved Confidence	"I feel like I personally was a lot more involved in it wasn't just a straight lecture, do this test do this experiment then get out. I feel like everything that was presented to us involved us in some way shape or form it regarded our opinions and validated them. So in comparison to other science classes I've taken it changed my opinion for the better regarding science and I would do it again actually."

Students often discussed being weak in science and mentioned feeling inadequate for a variety of reasons. Others discussed how they had previously been told they were not good enough or smart enough to participate in math and science. Fortunately, it seems that this class has a positive impact on the students and their confidence in their science abilities. These findings and associated quotes are shown in Table 8.

Science & Sustainability

All students interviewed expressed that they understood there to be a connection between science and sustainability. They mentioned the interdisciplinary aspects 19 times and generally explained how they saw science and sustainability as connected 23 times.

Table 9

Science and sustainability categories and supporting quotes.

Category	Supporting Quotation
Science Supporting Sustainability	"[Science and sustainability are] almost one and the same. I mean you need your science to understand what you're doing. You know, we're a people that need numbers and substance and tangible information to understand. We can't just, you know like "oh if you cut the water off we'll go save the planet!" Where's the proof? So you need that backup, especially today, we need proof."
Tribal Management	"Well, I have to know from the Salmon restoration, salmon hatchery, near shore, offshore, I have to know about our climate, I have to know about our timber, our land, our wetlands, our... I need to know how everything works. I have to build relationships with all these people. All these different entities -- state, federal, and Tribal."
Science & Sustainability Interconnection	"I don't think there's a science that doesn't, I guess correlate, with sustainability. I think anything you, I was trying to think of the sciences but it's like, I think that anything you talk about in science can relate to sustainability. I think it would be very difficult for you to come up with one that didn't. I mean, some people, they think geologists don't deal with that, but we learned that they do."

Some noted how without scientific understanding and evidence we would not be able to tackle environmental sustainability issues. Some describe how working with the Tribe requires their knowledge to bridge science and sustainability in order to solve problems and get work done. Others had a hard time even parsing science and sustainability apart from one another. These findings and associated quotes are shown in Table 9.

Science Skills

All of the interviewees mentioned at least one topic related to understanding science and growing their science skills. There were 23 examples of explicit content knowledge being shared and nine times that science skills were mentioned. Science was defined 10 times and sustainability was defined 28 times. There were 31 instances of how students thought they could participate in science and 26 instances of how to participate in sustainability.

Science skills that were stated included experimenting, testing, observing the natural environment, seeking science information from valid sources, identifying facts, critical thinking, and asking questions. A large number of content knowledge facts were also recording during the interviews.

Additionally, students were asked to define both science and sustainability. The answers range greatly, but showed that students had internalized their ideas about both subjects. Students provided well-conceived definitions of science and sustainability as both separate and interconnected subjects (shown in Table 10). These gains in science skills, content knowledge, and the ability to broadly explain science and sustainability indicate that learning did in fact take place throughout the course.

Table 10

Defining science and sustainability.

Definition	Supporting Quotation
Science definition	"Science has to do with like the world, the world around us, and the climate, the education of science, or biology. Like we learned about soil and how we need it and I just learned a lot from this class and it's only been like a few weeks."
Sustainability definition	"I think sustainability really is about living on this planet with all of, with everyone and these creatures in the best way possible and I think that's probably, I mean it's a very new thought to western culture, whereas, indigenous people, they've been doing this for, since time immemorial. They've been living sustainable."
Science & Sustainability shared definition	"When it comes to science and how we look at things and how we look at things and how we observe things, whether that be in a different field of science, biology, or geology, or whatever, it call comes back to being able to sustain it because that's how we make those observations. We observe that if we don't sustain it, animals for example go extinct. They weren't sustained and then we are able to observe the negative impacts that has on the environment. But at the same time because we've let that animal go extinct we can't observe that now, the scientific process for that has ended. So in order to not only maintain our scientific observations but increase them, that depends on sustaining what we have. And increasing what we have."

Pedagogy Positives

There were eight out of 10 students who mentioned curricular or pedagogical components of the class and why they like them. These general pedagogical positives were mentioned 18 times. In particular, "hands-on" labs and classroom activities were often mentioned. Students were adamant that the amount of hands-on activities made a large impact for them and that this should be included more heavily in all science classes:

The other curricular components that people seemed to like the most include: interdisciplinary topics, connecting science and sustainability to their lives, practical applications, covering topics that interest them (i.e. sustainability of hemp production), connection to culture, dissection, experiments, activities that they could do at home with their families, material that was at a true introductory level, many different subjects covered in one class, and connecting to local environmental and social issues. Overall, all interviewed students had a positive experience in their science course and saw value in the combined science and sustainability curriculum. Examples are shown in Table 11.

Table 11

Pedagogical approaches that worked and supporting quotes.

Approach	Supporting quotations
Hands-on	"When you do a lab and you can see all of this sediment that comes out of a free flowing water and then you see what happens to it when it's dammed, I think it definitely hits home. And then you realize "oh wow, these things are holding in a lot of sediment" and then if you've learned about what sediment does for the environment... you're kind of like 'oh shoot! That's not good!' So I think that lab definitely helps."
Practical Application	"My experience learning science through the lens of sustainability... It was a good experience. I appreciate that science is being taught through that lens because it's important that individuals who are going to be going out in the world with their degrees, taking on the world, understand that when they get in to whatever job they may end up in, that they understand that there are a lot of different things that impact our planet negatively and they can be the change in their company or their corporation or if they're scientists themselves they, you know, get that base understanding."
Personal Life	"I thought it was I thought it went over well. I enjoyed the class very much and I feel that everything that we went over is readily applicable to things that I can do in my life and things that you can make sustainable or that relate to sustainability more than I would have initially thought. So in terms of how the class was presented through that lens of sustainability I thought it was enjoyable and I thought it was very beneficial for my personal knowledge and actions that I can improve upon."

Discussion

In this preliminary examination, the impact of implementing the SE model in science courses at a TCU has shown to be positive. Students were very receptive to the combined science and sustainability content and interviews suggest the students see the two disciplines as one interdependent topic. The results of the surveys indicate that students obtained increases in science and sustainability literacy at the completion of the course. Interviews revealed that students' own unique science identities connected to and were supported by the SE curriculum and students saw increases in their science confidence and skills. Overall, the students generally enjoyed their experience in the course and saw a pronounced difference between the class and previous negative and traumatic STEM experiences.

During the interviews, students spoke about the connection between science and sustainability. All of the students understood the topics to be innately connected and saw value in learning about both topics simultaneously. In fact, it seems that teaching this way might actually be specifically useful for rural Tribal work where solving interdisciplinary problems that connect science, the environment, and the local economy are especially important. This means that it is useful to implement the SE model in science courses for practical reasons beyond learning basic science skills. Additionally, students may have been able to easily see science and sustainability as connected topics because of its similarity to Native Science, wherein science issues and "ways of knowing" are inherently interdisciplinary and multifaceted. Therefore, the integrated science and sustainability classroom may be successfully supporting traditional thought processes and cultural sovereignty.

This curriculum was successful because of its ability to connect with the unique science identity traits of each student. Additionally, now that five major science identity groups have been identified, there is a distinguishable path for growth of the SE model for TCU students. The identity categories of The Career Scientist, The Family Scientist, The Active Scientist, The Cultural Scientist, and The Personal Scientist each nicely connect with the prescriptions of the applied SE pedagogy. Therefore, it seems that the SE model does have the ability to positively impact the science identity of each student, which studies show can lead to long term academic impacts (Carlone & Johnson, 2008).

In particular, Career Scientists and Personal Scientists need science course materials to be practical, readily applicable, and connected to real world problems they may face one day either at work or at home. Meanwhile, the Family Scientists, Cultural Scientists, and Active Scientists need the course materials to be relevant to lives of those they love and the needs of their communities. Since most students have a mix of science identity traits, the science classroom must have a mix of curricular methods. This can be achieved through many of the recommended pedagogical approaches of SE model including community-based research, mentoring, experiential and applied learning opportunities, and learning communities.

Beyond connecting course material to personal traits and interests, it is also vital to consider the past negative and traumatic STEM occurrences many students have experienced and how the SE model curriculum can be used for mitigation. By resonating with the students' personal science identity, the SE curriculum can work to further develop and deepen their sense of science identity. This has been shown to further improve science confidence and propel students to continue in the sciences (Carlone & Johnson, 2008). The SE curriculum gives the students the ability to have positive experiences in the science classroom, which may help to overpower negative experiences they have had in the past. Due to the redefined nature of the SE curriculum, it seems that students have an opportunity for validation as budding scientists and they have the chance to overcome the trauma of not fitting into the ordinary western science mold.

Finally, there were specific pieces of the SE pedagogy that stood out to the students as being particularly useful and rewarding. Students felt very strongly about the hands-on aspect of the course and echoed again and again the importance of learning through doing. They enjoyed the experiential opportunities the course provided and cited them as being the most crucial to their learning and general interest in science. In implementing this curriculum providing such experiential learning opportunities should be vital. This might be the most important aspect of the four core components of the curriculum, or at least it was the most tangible part that students actually recognized. Either way, it is clear from this research that students are very responsive to the experiential learning aspect of the SE curriculum.

Overall, the results of this study support previous research that shows how important science identity, personal connection, and general relevancy of material are to Native students as well as others who are typically underrepresented in the sciences. Based on this research, it seems that implementing the SE curriculum might be one method of progressing science curriculum to better meet the needs of all students. It would be ideal if a larger scale study could be commissioned to see if these results hold true at other TCUs or with other groups of rural and marginalized students. Also, it would be useful to tweak the curriculum to find out which of the core components are truly the most valuable to the students. With this additional work to corroborate the findings of this study it could be possible to confidently proclaim that this curriculum is both viable and necessary for creating a more inclusive and successful science classroom.

Conclusion

As a global community we are currently living in tumultuous times. We must deal with interdisciplinary problems of environmental, social, political, and economic unrest. One of the largest and most defining issues of this Anthropocene epoch is the ever present and wicked problem of climate change. In order to overcome climate change, we must work together to create brilliant and resilient solutions and this cannot occur without a generation well educated problem solvers and creative thinkers. It is time for academia to recognize its importance in solving these problems and uplifting a diverse group people who are ready for the challenge. In particular STEM education needs to undergo a paradigm shift towards a more social and transdisciplinary model of SE for the changing world. This will help to educate scientists who can not only calculate, but also can think more holistically and deeply, and apply their complex thinking skills to multifaceted global problems.

There are many changes that must occur within STEM, especially in higher education, to make the discipline more relevant, useful, and equitable for the current era. One way that STEM education can evolve is by implementing the SE model. This means incorporating interdisciplinary topics into science courses by means of research-based projects, learning communities, experiential learning, and interconnected issues of local and global sustainability, with the goal of developing higher order cognitive skills. This could create students better prepared to analytically tackle modern problems. Additionally, STEM must evolve by creating a more inclusive environment for People of Color, women, Native Americans, and other groups who have been traditionally excluded from science. This needs to happen not only for general social justice and educational equity, but because we need all people and all unique points of view in order to combat the combined scientific and societal challenges we are facing. This is especially important in communities, like rural reservations, whose economic and cultural wellbeing is tied to the land and natural resources.

This research examined the relationship between implementing the SE curriculum in TCU science classes and impacts on the students' science identity and learning outcomes. By means of interviews and surveys, students' experiences in integrated science and sustainability courses were explored. The findings indicate that indeed science and sustainability curriculum can be successfully combined and have positive impacts on students who have been historically excluded in the sciences. For instance, the interdisciplinary aspect of the curriculum proved particularly useful for local Tribal work and community concerns on the reservation. Additionally, the hands-on and experiential learning approach was especially engaging to the students and worked to increase their interest in science and science skills. Most importantly, the SE curriculum naturally found ways of connecting with the student's personal science identities, which has shown to be a key component in developing future scientists (Carlone & Johnson, 2008).

These results are from a small, preliminary study, but are positive and useful, nonetheless. More work must be done to further understand how this type of curriculum impacts students over time, how it effects other groups of students (i.e. other HEGs and/or rural populations), and which aspects of the curriculum are more vital to reaching both science and equity goals. However, these positive results can have immediate use. There was nothing in the findings of this research that indicate any negative impacts, and overall students were more thoroughly enjoying their science experience and combatting previous STEM traumas. Therefore, at minimum the institution where this study took place can continue to implement these types of STEM courses and hopefully continue to monitor their impacts on the students.

It appears that by combining STEM courses with the SE curriculum an advantageous learning environment was created for the TCU students in this study. Research shows that similar pedagogical techniques also tend to be valuable for other HEGs. Therefore, it is possible that implementing the SE model can evolve STEM to meet the needs of a diverse set of students while also better preparing all students to solve the complex interdisciplinary problems that are threatening our communities on a local and global scale.

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I would like to thank the Tribal college, the Nation, the Education Department, the reservation community, and the students for co-creating this sustainability education model with me. I deeply appreciate being part of this community for nearly a decade and the relationships we built together (and will surely continue to build into the future). This research was completed during my Master's degree program before I learned many things about research and engagement with Indigenous peoples. In retrospect, all my students and colleagues could have been involved in manuscript development and listed as co-authors (or honored in a way of their choosing). I regret this missed opportunity to integrate everyone, and I will not make this mistake again in the future. I have decided to share this work because my students thrived in my science courses with the integrated sustainability education model, and this approach must be shared with hope that other educators can build from this foundation to improve pedagogy and curriculum for the benefit of Indigenous scholars.

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About the Author

Liliana Caughman, PhD. is a postdoctoral researcher, working with the Earth Systems Science for the Anthropocene (ESSA) network at Arizona State University. Her research focuses on how processes relate to outcomes, specifically in collaborative and community-based transformation and climate justice initiatives. Through her work, she also aims to evolve academia to better serve the pressing needs of the modern era, with a focus on diversity, equity, inclusion, and justice in STEM. She taught at Northwest Indian College for over six years and now at ASU Liliana is a Co-PI on an NSF Racial Equity in STEM grant focused on Indigenous graduate education. Liliana.caughman@asu.edu

Appendix

INTEREST IN SCIENCE (Adult version)

The Interest in Science questionnaire on page 3 measures general interest in learning science topics and engaging in scientific activities among adults. Interest in science is considered a key driver to pursuing science careers in youth (Tai, et al. 2006, Maltese and Tai 2010) and sustained lifelong learning and engagement in adults (Dabney et al. 2011, Falk, et al. 2007). We define interest as it relates to science and the environment as "the degree to which an individual assigns personal relevance to a science topic, activity, environmental issue, or the scientific endeavor." Over time, this type of interest can lead to sustained engagement, motivation, and can support identity development as a science learner (National Research Council 2009).

About the Questionnaire

The questionnaire contains 12 items total, and can be administered either online, by telephone, or via paper. It should take about 10 minutes to administer. This version of the questionnaire can be administered as a pretest and/or posttest. Please contact us if you would like to administer a retrospective pre-post version of this scale.

This questionnaire was developed and tested in the context of a variety of informal science learning settings (primarily with participants of Citizen Science projects). Because Citizen Science participants are typically involved in learning and doing science, we recommend implementing the full questionnaire.

Cleaning your data

Some project participants will not respond as carefully as you might hope. It is important to clean your data to account for this. Once you have entered the data into a spreadsheet such as Microsoft Excel, keep the original as a master, and make a copy from which to work from. Do the following simple checks:

1.) Go down each row (i.e., individual participant) and look across the set of responses for that participant – if two or more responses are missing, exclude that row from your analysis.
2.) Once again, go down each row (participant) and look across the set of responses. Then scroll through the rows looking for sets where all of the responses are the same.
3.)

In general, seeing the same response across all of the items is an indication that the respondent was not reading the items carefully. We recommend excluding sets where all answers are the same from your analysis *unless* the answers are all 3s, as many respondents do legitimately use midpoint responses to all questions.

Scoring instructions

These instructions pertain to the full 16-item questionnaire: Interest in Science (Adult version). Once you have implemented the questionnaire on page 3 and have your data in a spreadsheet, calculate a score for interest in science:

1.) Average together the scores for all of the items for each participant (score should be between 1-5).
2.) You can also average together the overall scores from all of your participants for an overall group score (score should be between 1-5).

Average scores below 3 indicate low levels of interest in learning or doing science activities.

Note: if you are administering the questionnaire before and after program participation and comparing the two sets of scores as part of a pre-post evaluation, you might want to consider first grouping your participants into those who started out relatively low in interest and those who started out relatively high in interest. While it is reasonable to expect an increase among participants who started out relatively low, you should not expect to see much, if any, increase in those who started out already quite high in their interest. You should consider merely maintaining that high level as a positive outcome.

INTEREST IN SCIENCE (ADULT VERSION) (remove title before administering)

Please indicate how much you DISAGREE or AGREE with each of the following statements by placing an X in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

Choose one answer in each row.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I want to learn more about the biological sciences (e.g. ecology, zoology, evolutionary biology).	1	2	3	4	5
2. I like to engage in science-related hobbies in my free time.	1	2	3	4	5
3. I want to understand how processes in nature work (e.g. how birds migrate, why leaves change color, how bees make honey, etc.)	1	2	3	4	5
4. I often visit science-related web sites.	1	2	3	4	5
5. I enjoy learning about new scientific discoveries or inventions.	1	2	3	4	5

6. Other people would describe me as a “science person.”	1	2	3	4	5
7. I am very interested in the natural sciences.	1	2	3	4	5
8. I enjoy reading about science-related topics.	1	2	3	4	5
9. I like to observe birds, butterflies, bugs, or other things in nature.	1	2	3	4	5
10. I enjoy talking about science topics with others.	1	2	3	4	5
11. I am interested in learning more about the physical sciences (chemistry, physics, astronomy, and geology).	1	2	3	4	5
12. I enjoy looking at information presented in scientific tables and graphs.	1	2	3	4	5

* This scale is still in development and subject to possible changes as testing continues

NATURE RELATEDNESS (Short Form)

The Nature Relatedness Short Form questionnaire (see page 2) is adapted from the original Nature Relatedness Scale (Nisbet et al. 2009) and the shortened version (Nisbet et al. 2013). This scale is intended to measures one’s interest in the natural world. We define interest here as a tendency to direct one’s attention toward, be aware of, and attribute importance to the natural world. Interest in the natural world is associated with persistence in the pursuit of positive environmental activities. This questionnaire was developed and tested in the context of informal science learning environments (primarily with participants of Citizen Science projects).

Cleaning your data

Some project participants will not respond as carefully as you might hope. It is important to clean your data to account for this. Once you have entered the data into a spreadsheet such as Microsoft Excel, keep the original as a master, and make a copy from which to work from. Do the following simple checks:

1.) Go down each row (observer) and look across the set of responses for that observer – if two or more responses are missing, exclude that row from your analysis.
2.) Once again, go down each row (observer) and look across the set of responses for that observer. Then scroll through the rows looking for sets where all of the responses are the same.

Scoring instructions

Once you have implemented the Nature Relatedness (Short Form) questionnaire and have cleaned your data, calculate the overall scores for individual participants and for the group of participants as a whole as follows:

1.) Average together the scores for all of the items for each participant.
2.) You can then average together the overall scores from all of your participants for an overall all group score.

*Note. If you are administering the questionnaire before and after program participation and comparing the two sets of scores as part of an evaluation of your program, you might want to consider first grouping your participants into those who started out relatively low in interest and those who started out relatively high in interest. While it is reasonable to expect an increase among participants who started out relatively low in interest, you should not expect to see much, if any, increase in those who started out already quite interested in the natural world. You should consider merely maintaining that high level as a positive outcome.

3.) Scores below 3 indicate low levels of interest in the natural world.

NATURE RELATEDNESS (Short Form- adapted) **(remove title before administering)**

Please indicate how much you **DISAGREE** or **AGREE** with each of the following statements by placing an **X** in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

	Strongly Disagree	Disagree	Neutral	Agree	Agree Strongly
1. My relationship to nature is an important part of who I am.*	1	2	3	4	5
2. I feel very connected to all living things and the earth.*	1	2	3	4	5
3. I am not separate from nature, but a part of nature.	1	2	3	4	5
4. I always think about how my actions affect the environment.*	1	2	3	4	5
5. I am very aware of environmental issues.	1	2	3	4	5
6. Even in the middle of the city, I notice nature around me.	1	2	3	4	5

- This scale is still in development and subject to possible changes as testing continues
- * One of the six items included in the Short Version of the scale: Nisbet EK, Zelenski JM. 2013. The NR-6: a new brief measure of nature relatedness. Front Psychol. (4):813.
- Nisbet E. K. L., Zelenski J. M., Murphy S. A. (2009). The nature relatedness scale: linking individuals' connection with nature to environmental concern and behavior. Environ. Behav. 41, 715–740 10.1177/0013916508318748

SELF-EFFICACY FOR ENVIRONMENTAL ACTION

The Self-Efficacy for Environmental Action questionnaire (see page 2) measures one's confidence in their ability to effectively address environmental concerns. Self-efficacy for environmental action is associated with persistence in the pursuit of positive environmental activities. This questionnaire was developed and tested in the context of informal science learning environments (primarily with participants of Citizen Science projects).

Cleaning your data

Some project participants will not respond as carefully as you might hope. It is important to clean your data to account for this. Once you have entered the data into a spreadsheet such as Microsoft Excel, keep the original as a master, and make a copy from which to work. Do the following simple checks:

3.) Go down each row (observer) and look across the set of responses for that observer – if two or more responses are missing, exclude that row from your analysis.
4.) Once again, go down each row (observer) and look across the set of responses for that observer. Then scroll through the rows looking for sets where all of the responses are the same.

    In general, seeing the same response across all of the items is an indication that the respondent was not reading the items carefully. In particular, items 6 and 8 are "reverse coded," which means they are worded in such a way that they should receive opposite answers from other questions if respondents are answering all questions in a consistent manner. We recommend excluding sets where all answers are the same from your analysis *unless* the answers are all 3s, as many respondents do legitimately use midpoint responses to all questions.

Scoring instructions

Once you have implemented the Self-Efficacy for Environmental Action questionnaire and have cleaned your data, calculate the self-efficacy score as follows:

4.) Reverse the responses to questions 6 and 8 such that 1s become 5s, 2s become 4s, 3s stay 3s, 4s become 2s, and 5s become 1s.
5.) Average together the scores for all of the items for each participant.
6.) You can then average together the overall scores from all of your participants for an overall all group score.

*Note. If you are administering the questionnaire before and after program participation and comparing the two sets of scores as part of an evaluation of your program, you might want to consider first grouping your participants into those who started out relatively low in self-efficacy and those who started out relatively high in self-efficacy. While it is reasonable to expect an increase among participants who started out relatively low in self-efficacy, you should not expect to see much, if any, increase in those who started out already quite confident in their abilities. You should consider merely maintaining that high level as a positive outcome.

7.) Scores below 3 indicate low levels of confidence in one's ability to effectively address environmental concerns.

SELF-EFFICACY FOR ENVIRONMENTAL ACTION

Please indicate how much you **DISAGREE** or **AGREE** with each of the following statements about your influence on the environment by placing an **X** in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I feel confident in my ability to help protect the planet.	1	2	3	4	5
2. I am capable of making a positive impact on the environment.	1	2	3	4	5
3. I am able to help take care of nature.	1	2	3	4	5
4. I believe I can contribute to solutions to environmental problems by my actions.	1	2	3	4	5
5. Compared to other people, I think I can make a positive impact on the	1	2	3	4	5
6. I don't think I can make any difference in solving environmental problems.	1	2	3	4	5
7. I believe that I personally, working with others, can help solve environmental	1	2	3	4	5
8. It's hard for me to imagine myself helping to protect the planet.	1	2	3	4	5

* This scale is still in development and subject to possible changes as testing continues

SELF-EFFICACY FOR LEARNING AND DOING SCIENCE

The Self-Efficacy for Learning and Doing Science questionnaire (see page 2) measures one's confidence in learning science topics, engaging in scientific activities, and more generally in being a scientist. Self-efficacy for science is associated with persistence in the pursuit of science-oriented activities. This questionnaire was developed and tested in the context of informal science learning environments (primarily with participants of Citizen Science projects).

Cleaning your data

Some project participants will not respond as carefully as you might hope. It is important to clean your data to account for this. Once you have entered the data into a spreadsheet such as Microsoft Excel, keep the original as a master, and make a copy from which to work. Do the following simple checks:

5.) Go down each row (observer) and look across the set of responses for that observer – if two or more responses are missing, exclude that row from your analysis.

6.) Once again, go down each row (observer) and look across the set of responses for that observer. Then scroll through the rows looking for sets where all of the responses are the same.

In general, seeing the same response across all of the items is an indication that the respondent was not reading the items carefully. In particular, items 3 and 7 are "reverse coded," which means they are worded in such a way that they should receive opposite answers from other questions if respondents are answering all questions in a consistent manner. We recommend excluding sets where all answers are the same from your analysis *unless* the answers are all 3s, as many respondents do legitimately use midpoint responses to all questions.

Scoring instructions

Once you have implemented the Self-Efficacy for Learning and Doing Science questionnaire and have cleaned your data, calculate the self-efficacy score as follows:

8.) Reverse the responses to questions 3 and 7 such that 1s become 5s, 2s become 4s, 3s stay 3s, 4s become 2s, and 5s become 1s.
9.) Average together the scores for all of the items for each participant.
10.) You can also average together the overall scores from all of your participants for an overall group score.

4.) Scores below 3 indicate low levels of confidence in learning project-related information and/or participating in project activities. Given that the questionnaire includes separate sets of items for learning (items 1-4) and doing (items 5-8), you might want to average those sets of responses (either for individual or group) separately to investigate whether participants are more or less confident with one or the other concept.

Note that if you are administering the questionnaire before and after program participation and comparing the two sets of scores as part of a pre-post evaluation, you might want to consider first grouping your participants into those who started out relatively low in self-efficacy and those who started out relatively high in self-efficacy. While it is reasonable to expect an increase among participants who started out relatively low in self-efficacy, you should not expect to see much, if any, increase in those who started out already quite confident in their abilities. You should consider merely maintaining that high level as a positive outcome.

SELF-EFFICACY FOR LEARNING AND DOING SCIENCE

Please indicate how much you **DISAGREE** or **AGREE** with each of the following statements about science by placing an **X** in the appropriate column. Please respond as you really feel, rather than how you think "most people" feel.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
These statements are about how you feel about learning and understanding science topics.					
1. I think I'm pretty good at understanding science topics.	1	2	3	4	5
2. Compared to other people my age, I think I can quickly understand new	1	2	3	4	5
3. It takes me a long time to understand new science topics.	1	2	3	4	5

4. I feel confident in my ability to explain science topics to others.	1	2	3	4	5
These statements are about how you feel about <u>doing scientific activities</u>.					
5. I think I'm pretty good at following instructions for scientific activities.	1	2	3	4	5
6. Compared to other people my age, I think I can do scientific activities	1	2	3	4	5
7. It takes me a long time to understand how to do scientific activities.	1	2	3	4	5
8. I feel confident about my ability to explain how to do scientific activities to	1	2	3	4	5

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Co-designing a Rural Research Practice Partnership to Design and Support STEM Pathways for Rural Youth

Srinjita Bhaduri,[1] Quentin Biddy,[1] Colin Hennessy Elliott,[1] Jennifer Jacobs,[1] Melissa Rummel,[2] John Ristvey, [2] Tammy Sumner,[1] Mimi Recker[3]
[1]University of Colorado Boulder
[2]University Corporation for Atmospheric Research (UCAR)
[3]Utah State University

Rural students, schools, and communities have unique challenges that hinder academic achievement, growth, and opportunities, compared to other locales. While there is a need to study this community more, there is also a pressing need to bring the local community members together to support the future generation of learners in developing pathways that lead them to future career opportunities. This article focuses on how a Research Practice Partnership (RPP) can be developed in rural communities to support STEM pathways for local middle school youth. RPPs are often described as long-term collaborations between both researchers and practitioners in which the participating partners leverage research to address specific persistent problems of practice. We present findings from a developing design-based RPP focused on bringing community members and organizations together to co-design opportunities for underserved youth in rural mountain communities.

***Keywords*: rural, STEM pathway, research practice partnership (RPP), STEM mentoring, co-design, middle-school, programmable sensor technology, 3D printing**

Youth residing in rural areas often have fewer opportunities to engage with Science, Technology, Engineering, and Mathematics (STEM) through learning experiences in both in-school and out-of-school-time (OST) contexts (Arnold et. al., 2005; Saw & Agger, 2021). Youth persistence and continued engagement are common goals in STEM learning (Leos-Urbel, 2015) and can be challenging in rural settings (Saw & Agger, 2021). STEM learning interventions that are personally relevant to youth have been found to make meaningful connections between STEM learning experiences and youths' lives in their school and their community, especially for youth with low socioeconomic status and from underserved groups (Harackiewicz & Hulleman, 2010; Hulleman & Harackiewicz, 2009). Grounding science and engineering design challenges within a local STEM ecosystem can empower underserved youth to develop their narratives and understandings of their local communities (Taylor & Hall, 2013). Similarly, attending to local knowledge enables youth to see connections between emerging technologies and their local spaces, including the cultural capital they already possess (Zwiers, 2007). According to Bartko (2005), "youth who are committed to and highly active in an endeavor are more likely to continue in that endeavor, [and] see it as part of their identity." Anchoring learning in exploring phenomena and addressing locally relevant challenges enables youth to build interests from their everyday experiences and explore how STEM contributes to their lives and community (Avery, 2013; Bhaduri et al., 2018; Bell et al., 2013).

This article stems from working in a mountain community (called Mountain County) that has many of the characteristics of a rural place including youth from traditionally underrepresented groups in STEM (Saw & Agger, 2021). Specifically, this mountain community has a large population of English language learners and youth from immigrant communities, groups that have been shown in other communities to experience lower levels of confidence in their abilities and reduced participation and retention rates in STEM (Beyer, 2014; Fisher & Margolis, 2003; Fox et al., 2009). Research suggests almost one in five U.S. students attends a rural school, and very little is known about their achievements and academic growth (Johnson et al., 2021). Providing explicit opportunities for youth to relate STEM learning to their lives positively impacts interest development and persistence in the field (Harackiewicz & Hulleman, 2010). Additionally, understanding the local STEM ecosystem can help youth and parents better navigate the existing STEM opportunities and pathways and aid in developing new STEM pathways (Bricker & Bell, 2014).

To develop and support STEM opportunities for youth, one approach is to bring together community members and organizations as a Research Practice Partnership (RPP) focused on STEM opportunities for youth. In an RPP, members collaboratively develop a common body of knowledge, shared practices, and a set of values while cultivating a productive community (MacPhail et al., 2014). These partnerships working in a focused “niche” aim to offer solutions such as “educational tools, materials, and practical guidance” (Cohen & Mehta, 2017, p. 2). Our work builds on this literature to establish and study a developing design-based RPP (Coburn et al., 2013) focused on supporting youth in a rural Western US community. Thus, using RPP for taking the existing STEM ecosystem and turning it from opportunity-based to something more collaborative and eventually interconnected.

Within Mountain County, program funding is readily available due to philanthropy and other funding sources. Yet the funds are not spread equally across the county due to the funding sources being localized in the more affluent parts of the county. As a result, the main limiting factor for the various in-school and OST programming is the number of youth in the county available to participate in these programs. This creates an ecosystem where organizations compete for youth participants sometimes more than funding. Additionally, the network of opportunities is often much less visible to the students who could benefit from them. One primary goal is to create an RPP model with structures, strategies, and tools that encourage and support collaborative relationships between people and organizations across the local STEM ecosystem that serve to build and support coherent STEM pathways for local youth. This study explores what such an RPP looks like in a rural context and how, as a whole, the RPP supports rural students to see and have access to STEM career pathways.

To explore how youth engage in opportunities within the rural STEM learning landscape of this community, we identified three interacting components 1) a community partnership working together to support youth engagement in STEM career pathways, 2) in school and OST curricula where youth use emerging technologies, such as 3D printing and programmable sensor technologies, to engage in science and engineering investigations, and 3) integrated career experiences that encourage youth to make connections with local mentors in STEM and computing fields. These three components can begin to form a model that essentially outlines the partnership: e.g., integrating technology into existing in-school and OST instruction, using local community-based mentors, designing OST experiences, and brokering relationships between these people and organizations.

This article, elaborates on each of these components, how they interact, and how the partners work together to provide opportunities for youth to forge STEM learning pathways within this rural STEM ecosystem.

Background

Our work draws from prior research on STEM ecosystems and the STEM landscape in rural settings, developing and maintaining RPPs, and ways to co-design and adapt large RPPs for rural communities.

Rural STEM Ecosystems and Landscapes

Historically, rural youth faced unprecedented challenges preparing for STEM postsecondary education and careers compared to youth in urban areas (Schafft & Jackson, 2011). Often, they encounter issues of geographic isolation, lack of access to advanced coursework in STEM and related fields, and face economic challenges that hinder their educational opportunities and future employment (Ihrig et al., 2018; Brenner, 2016). Prior research has identified additional challenges that rural communities face, such as a lack of teaching and cultural resources, including libraries, zoos, and museums (Johnson et al., 2021). Tofel-Grehl and colleagues (2021) suggest the need to examine rural youth experience, understand rural educator experiences, and opportunities available to facilitate a rural educational change. We posit that youth experience seeing and embarking on different pathways through a local STEM landscape.

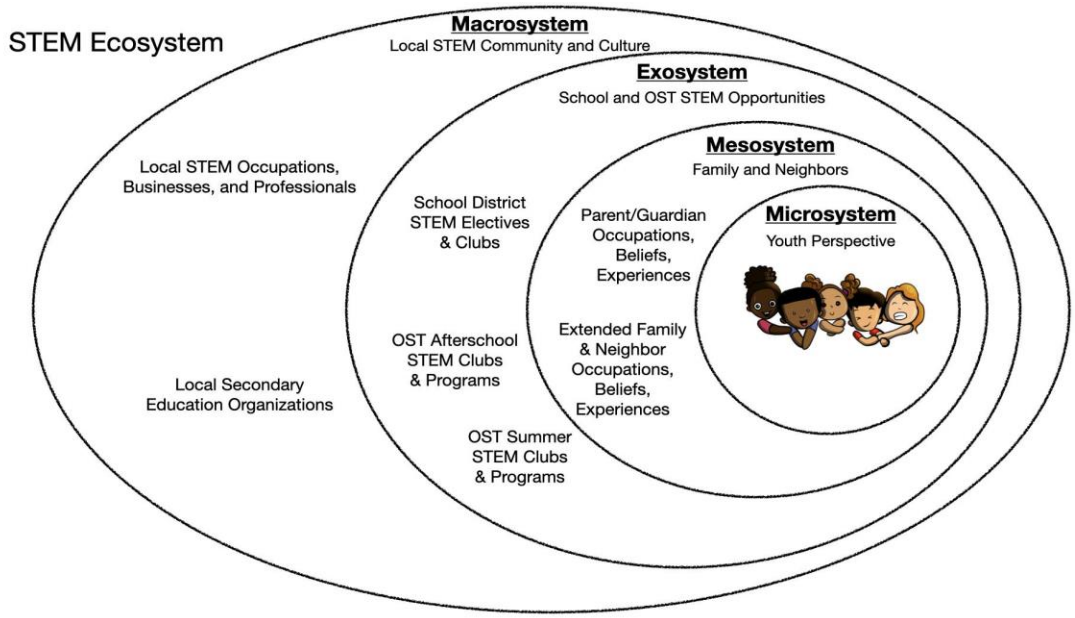
Although rural communities face several challenges, there are also assets from which rural youth, schools, and communities can potentially benefit, leading to positive achievement. Rural communities are tightly knitted, and educators tend to have closer relationships with youth and their families and communities, resulting in a better perception of youth learning needs (DeYoung, 1987; Johnson et al., 2021). Such tight-knit communities contribute to a supportive ethos in smaller communities (Johnson et al., 2021). Rural communities often have a supportive ethos but have limited in-school and out-of-school opportunities for youth (Tofel-Grehl et al., 2021). There is competition among the existing organizations that provide such opportunities to youth since they compete to work with the same small group of youth, duplicating community resources. It raises the need to consider rural STEM learning ecosystems where youth can quickly identify the opportunities available to them and take advantage to better contribute to their learning pathways.

Recent research has presented the benefits of using ecological perspectives to position different learning environments in relation to each other (Dierking et al., 2021) (see Figure 1). From that perspective, a STEM learning ecosystem comprises diverse resources—both in and out of school, where youth develop an understanding of different STEM interests and participation pathways (SIPPs) while traversing the ecosystem (Dierking et al., 2021; Falk et al., 2016). Therefore, we posit that both a STEM ecosystem and a STEM landscape perspective are essential for understanding how STEM pathways are created and sustained at the partner level

(STEM Ecosystem) and how youth and parents navigate these STEM pathways from the youth perspective (STEM Landscape).

Figure 1

Local STEM Ecosystem



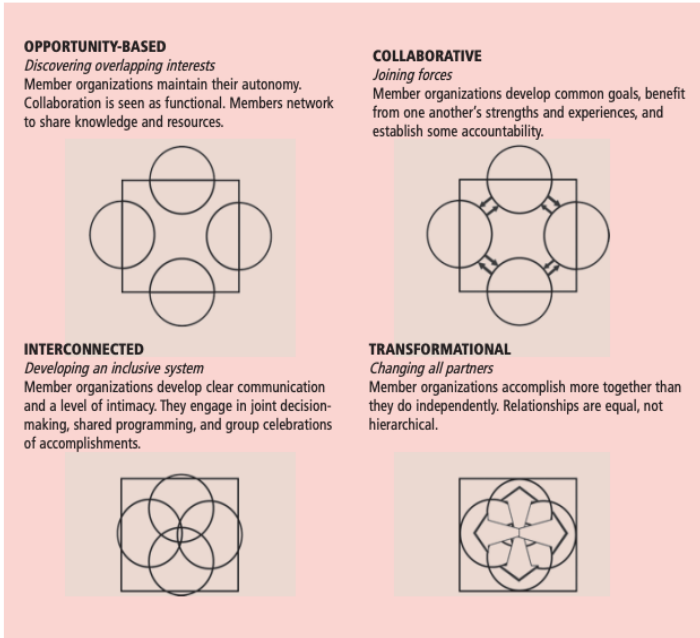
Note: Adapted from Brofenbrenner, 1995.

Research Practice Partnerships (RPPs)

According to Coburn and colleagues (2013), RPPs are often described as long-term collaborations between researchers and practitioners. The participating partners leverage research to address specific persistent problems of practice. Three types of RPPs have been identified—research alliances, networked improvement communities, and design-based RPPs (Coburn et al., 2013). Additionally, RPPs focused on educational reforms provide “organizational structure to facilitate sustained collaboration between researchers and practitioners to improve learning opportunities for students” (Henrick et al., 2017). RPPs that focus on a specific “niche” and work to create solutions such as “educational tools, materials, and practical guidance” are more successful than those that focus on larger-scale reforms and solutions (Cohen & Mehta, 2017, p. 2). Our project is working to establish and study the development of a new RPP focusing on supporting the creation and sustaining of STEM opportunities for underserved students in a rural Western US community. Henrick and colleagues (2017) identified five dimensions for effective RPPs: 1) Building trust and cultivating partnership relationships, 2) Conducting rigorous research to inform action, 3) Supporting the partner practice organization in achieving its goals, 4) Producing knowledge that can inform educational improvement efforts more broadly, and 5) Building capacity of the participating researchers, practitioners, practice organizations, and researcher organizations to engage in partnership work. Most RPPs develop through different partnership types (as in Figure 2) (Allen et al., 2020; Noam & Tillinger, 2004).

Figure 2

Partnership Typology



Note: (Allen et al., 2020; Noam & Tillinger, 2004).

The STEM Career Connections (STEMCC) project, in the second year of developing a new RPP, has progressed similarly through these typologies, starting with opportunity-based and can currently be described as a collaborative partnership. In a sense, the STEMCC model is the partnership, i.e., who is part of the ecosystem (researchers, teachers, mentors, etc.), what they are bringing to the table to support students to embark on a STEM career pathway, and how they support & complement each other in these efforts? We will expand on the development of this partnership further in this paper.

Co-design

This research builds on Yurkofsky and colleague's (2020) framework to examine how "co-design" can serve as an effective internal nurturing process for aligning partnership efforts. Co-design is a highly facilitated, team-based process where project stakeholders and researchers work together in well-defined roles. They design and iteratively refine an educational intervention to collect information on impacted educational practices and their context and engage in collaborative efforts to promote common understanding among different actors (Penuel et al., 2007; Roschelle et al., 2006). Co-design helps establish more realistic expectations and manage emergent tensions among educators, stakeholders, and researchers to work together toward an innovation goal. Within formal education, co-design involving researchers and educators can produce high-quality STEM curricula and build district and teacher capacity to implement innovative learning experiences (see, e.g., Bhaduri et al., 2019, 2021b; Chakarov et al., 2020, 2021; Penuel et al., 2007; Severance et al., 2016).

Building on prior work, our project engaged stakeholders and partners from the Mountain County community to co-design STEM learning curricula and activities for the local youth. Co-design took place over video conference meetings during the 2020-2021 school year and focused on what the future youth STEM learning experience would encompass (Bhaduri et al., 2021). These co-designed curricula have been implemented in multiple formal and informal settings in the same community.

Research Questions

The following research questions guided the development of this new RPP.

1. How can the development of collaborative relationships between community partners in a rural STEM ecosystem develop, build, and support STEM pathways that are more visible, navigable, and coherent for rural youth?
2. What tools and practices are involved in ensuring that existing and new STEM pathways are made available to youth through a developing and expansive rural RPP?

Theoretical Framework

Partnership Types

Our approach to developing a design-based RPP was inspired by prior work that suggests, in design-based RPPs, researchers and practitioners collaborate when building and studying solutions in real-world contexts while investigating ways to best support youth learning (Yurkofsky et al., 2020). Thus, taking the learnings from large urban districts and applying them to rural contexts by understanding ways to create a partnership “niche” within the context (Yurkofsky et al., 2020). Through this design-based RPP, our work emphasized the importance of practice and research by co-designing instructional materials for youth that can be implemented in-school and out-of-school (Cobb & Jackson, 2012). And finally, co-designing pathways for youth and advancing research and theory for the less studied, rural population (Johnson et al., 2021).

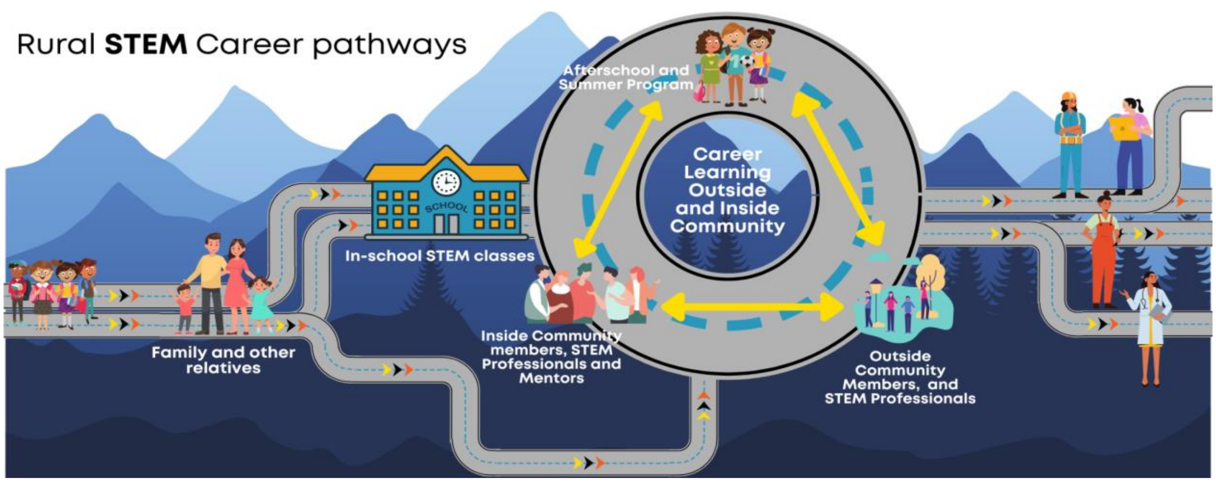
Drawing from prior work by Noam & Tillinger (2004), we use the partnership typology (see Figure 2) to describe the development of our RPP. We identified that the STEM ecosystem (see Figure 1) was rather competitive in Mountain County during our initial partnership building. Several community organizations, i.e., afterschool and OST programs, offer similar programs to youth, and the in-school curricula lacked STEM focus. Hence, the main limiting factor for the various in-school and OST programming was the number of participating youth in the county and the need for more STEM-focused curricula. As an RPP team, we identified community members and organizations with overlapping interests in creating STEM pathways for the rural youth residing in this community; in other words, it started as a functional partnership (Noam & Tillinger, 2004). After identifying common interests, this RPP focused on a common goal set by joining forces with community members and organizations to move to a collaborative partnership. The goal was to co-design STEM opportunities and access for the youth in the community and help them develop a better understanding of the STEM landscape from their perspective. While this RPP is in its second year, the aim is to move to a transformational partnership eventually. The different partners accomplish more goals together than they do when working independently. It allows all partners to change together and create equal relationships instead of maintaining a hierarchy (Noam & Tillinger, 2004). Building on this framework, our work investigates how co-designing with local partners enables youth to develop STEM applications within their everyday lives and connect with various STEM career pathways accessible in their communities.

STEM Pathways

Bricker and Bell (2014) outline STEM learning pathways as 'constellations of situated events' distributed across social and material spaces. From this perspective, individual youth's interests and participation in STEM are constantly in development across their participation in various settings as they develop relationships to larger, and differing, communities and engage in material practices. We build on this framework to articulate a STEM pathway as a set of connected experiences deliberately developed to increase youths' interest and participation in STEM opportunities local to the rural community of Mountain County. Part of this work is developing STEM experiences that are intentionally stitched together across in-school and OST learning spaces (both formal and informal) for middle school youth. Through the creation of multiple STEM-related interest pathways (see Figure 3), we place STEM learning at the center as interconnected processes developed from a constellation of situated events where youth can encounter multiple community connections to STEM and STEM careers, in afterschool programming, at summer camps, and in the youths' middle school classroom experiences. In other words, the development of a STEM pathway means making room for youth to imagine futures impacted by STEM. By focusing on designing and investigating these STEM pathways and their development, we can explore how the larger STEM ecosystem frames access to different visions of futures for participating youth and how they perceive pathways created at the STEM landscape level from the youth perspective.

Figure 3

Rural STEM career pathways as identified in the STEMCC project



Context and Methods

This project focused on developing a rural design-based RPP that can bring various stakeholders together to create, support, and sustain opportunities for middle school youth to engage in local STEM career pathways. According to the 2020 U.S. census, Mountain County has a population of around 55,000 and covers over 1500 square miles within a remote rural area of the Rocky Mountains in a midwestern state. The school district that serves this community contains 20 schools and around 7,000 students, with the district's minority enrollment at 55.8%.

Additionally, 38% of students are economically disadvantaged and eligible for federal free and reduced lunch. The student body of the school district is 44.2% White, 0.6% Black, 0.6% Asian or Asian/Pacific Islander, 52.1% Hispanic/Latino, 0.4% American Indian or Alaska Native, and 0% Native Hawaiian or other Pacific Islander. In addition, 2.1% of students are two or more races, and 0% have not specified their race or ethnicity. Also, 47% of students are female, and 53% are male. Of the student population, 33.9% of students are English language learners. As mentioned above, many of the current youth programs are competing for participants. Yet many youth, particularly those from minoritized populations, do not know about or have access to the full menu of options. One primary goal is to create structures, strategies, and tools for these organizations to collaborate to build and support coherent STEM pathways.

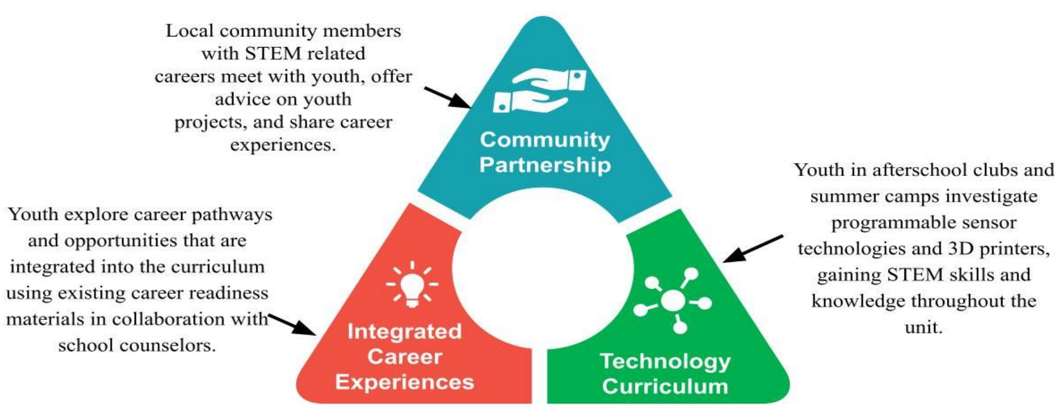
The STEMCC project is focused on developing an innovative career readiness model for both in and out of school settings that will profoundly increase the knowledge of and interest in STEM and computing careers for middle school youth within a rural mountain community who are often underserved in STEM fields. To achieve this goal, we have three integral components of the project (see Figure 4): 1) a community partnership working together to support youth engagement in STEM and computing career pathways, 2) a STEM curriculum where youth use advanced technologies (such as 3D printers or programmable sensors) to engage in science and engineering investigations and, 3) integrated career experiences that encourage youth to make personally-relevant connections with local STEM and computing occupations.

Participants

To develop an innovative STEM career readiness model, the STEMCC project has been working with local partners to bring together relevant stakeholders in the local rural community to develop relationships across the STEM ecosystem that can support existing STEM opportunities for youth and create and sustain new opportunities for youth to engage in STEM in ways that are relevant and meaningful to their local community.

Figure 4

STEM Career Connections (STEMCC) Project Overview



Local STEM Occupations, Businesses, and Professionals

The project works collaboratively with local STEM occupations, businesses, and professionals in multiple capacities. First, representatives from three local STEM-related businesses are participating in the project community STEM advisory group. Additionally, STEM professionals worked directly with youth as STEM mentors. A total of 46 STEM mentors worked with students during the 2020-2021 school year, 12 STEM mentors worked with students during the summer OST program, and 30 STEM mentors worked with students during the 2021-2022 school year. The mentors meet directly with students to make explicit connections between what students were doing in class or the OST program and how STEM is used in their local community as well as the STEM careers that exist within the local community.

Local Secondary Education Organizations

One representative from the local community college is currently participating in the project community STEM advisory group. The college offers programs leading to certification, associate's degrees, and bachelor's degrees, many of which are STEM-related and relevant to the careers offered in the local community and surrounding areas.

In-School Partner

Multiple stakeholders within the local rural school district actively participated in the project, including the school district's assistant superintendent, the college and career counselor coordinator, the career-X and Avid coordinator, two district educational technology specialists, and three STEM elective teachers from three different middle schools in the district.

Out-of-School-Time (OST) Organizations

Two organizations provide programming for OST learning experiences within the targeted rural community. One organization offers both afterschool and summer programming to youth in the community. The afterschool programming provided by this organization utilizes a club-based approach and focuses primarily on social-emotional needs and learning and partnered with the project to begin to offer STEM career-focused programming not previously offered. Through the 2021 summer program, 120 middle school youth participated in a four-week summer camp with one week dedicated to STEM and STEM career learning.

The second OST organization primarily offers after-school programming at the middle school level focused on STEM learning. During the 2020-2021 school year, five middle school youth participated in STEM project curriculum at one middle school. During the 2021-2022 school year, 64 middle school students participated in STEM project curriculum at five sites.

Youth Participants

Rural middle school youth in this community have participated in both in-school and OST project STEM activities. Youth participate in in-school STEM project activities through the STEM electives at four middle schools in the district. As a result of the work with the STEM elective teachers, around 700 middle school students participated in project STEM activities during the 2020-2021 school year, and 150 middle school students participated in project STEM activities. Project activities included designing, programming, and building sensor integrated physical computing systems; designing, revising, and creating 3D printed animal prosthetics; integrated STEM career connection lessons that were co-designed with the teachers and district college and career counselor coordinator; and engaging with local STEM mentors and guest speakers who worked with students to make explicit connections between what students were doing in class and STEM and STEM careers in their local community.

Table 1

List of data sources we collected and analyzed

Data Source Type	Description	Data Collected
Project Meeting Notes	We use the ongoing meeting notes document to keep everyone apprised of relevant information.	Every two weeks
Partner Surveys	Partners reflected on motivations for participating in the project, their experience being part of the advisory board, and suggestions for improving the experience.	After every implementation
Reflective Memos	Document what the project has accomplished over the past few months and reflect on project goals and our partnership toolkit framework. The guiding questions and key constructs for these memos are listed in Appendix A1.	Quarterly
Debrief Interviews	Elicit teacher and facilitator perceptions of the overall experience with the co-designed curriculum, resources, the collaboration, student engagement and perspective of STEM, and any other formative feedback.	Post-implementation, 9 teachers and program facilitators, 45-minute-long interviews
Semi-Structured Student Interviews	Gauge youth perspectives on the co-designed curricula and activities and elicit their perceptions of the curriculum, their understanding of the technology, knowledge of STEM in the community, and their STEM interest resulting from their participation in the unit.	Post-implementation, 4-5 youth from each implementation, students selected by teacher, 15-minute-long interviews
Focus Group	Gauge stakeholders' perception of the partnership development.	End of the year
External Evaluation Reports	Evaluation team for the STEMCC project administered surveys and conducted interviews with the main partners and STEM mentors participating in the project. This was provided as feedback to the project.	Every 4-6 months
Partner Communications	Email communications with partners were documented to track how the various relationships within the project developed over time and what tools and strategies helped cultivate these relationships	Weekly communication
Community STEM Advisory Group Meeting Notes and Observations	Detailed notes from all internal research planning meetings and detailed observation notes from advisory meetings. At meetings, stakeholders conducted activities and discussed STEM opportunities for youth leading to collective imagining of future opportunities.	Quarterly

Data Sources

We collected data in various forms from partners at different points of the partnership development and as a part of the project activities. The data sources and their description are listed in Table 1.

Data Analysis

Data were analyzed using a constant comparative method (Creswell, 2013; Glaser & Strauss, 1967). Members of the research team used open coding to analyze the data to determine what topics or themes might emerge that accurately conveyed the nature of the tools and practices involved in the development of the rural design-based RPP and the resulting youth STEM pathways (as recommended in Merriam, 2002; Saldaña, 2021; Strauss & Corbin, 1990). This qualitative analysis of each data source involved identifying themes that relate to the research questions. At least two researchers analyzed the data and discussed what they noted with the larger research team (as recommended by Merriam, 2002; Stake, 1995). The researchers then resolved any coding disagreements. Our team consolidated codes after the first coding focusing on best tools and practices for developing rural RPPs. This focus allowed us to better understand the rural space the different community partners were situated in and consider the local youth perspective.

Then by methodological triangulation (Bekhet & Zauszniewski, 2012) of the other data sources, we validated our findings and understanding of the common themes to develop the RPP resulting in rural STEM pathways for youth. Furthermore, this coding allowed us to explore the expected and unexpected lessons learned through the developing RPP. After several iterations, we agreed to document the key themes and review them after each implementation and partnership meeting. Finally, we created analytic memos noting when instances of each identified theme were explicitly evident. We then reviewed and discussed each other's memos and analysis notes and collaboratively considered their interpretations, ultimately reaching a consensus on what to include in this article (as recommended in Merriam, 2002; Stake, 1995).

Findings

Our findings are presented in the form of our two research questions.

RQ1: Collaborative Development of a Rural Design-based STEM Research Practice Partnership.

Figure 5 outlines the activities involved in the development of this new rural Research Practice Partnership that brought various stakeholders together to create, support, and sustain opportunities for middle school youth to engage in local STEM pathways.

Year 1

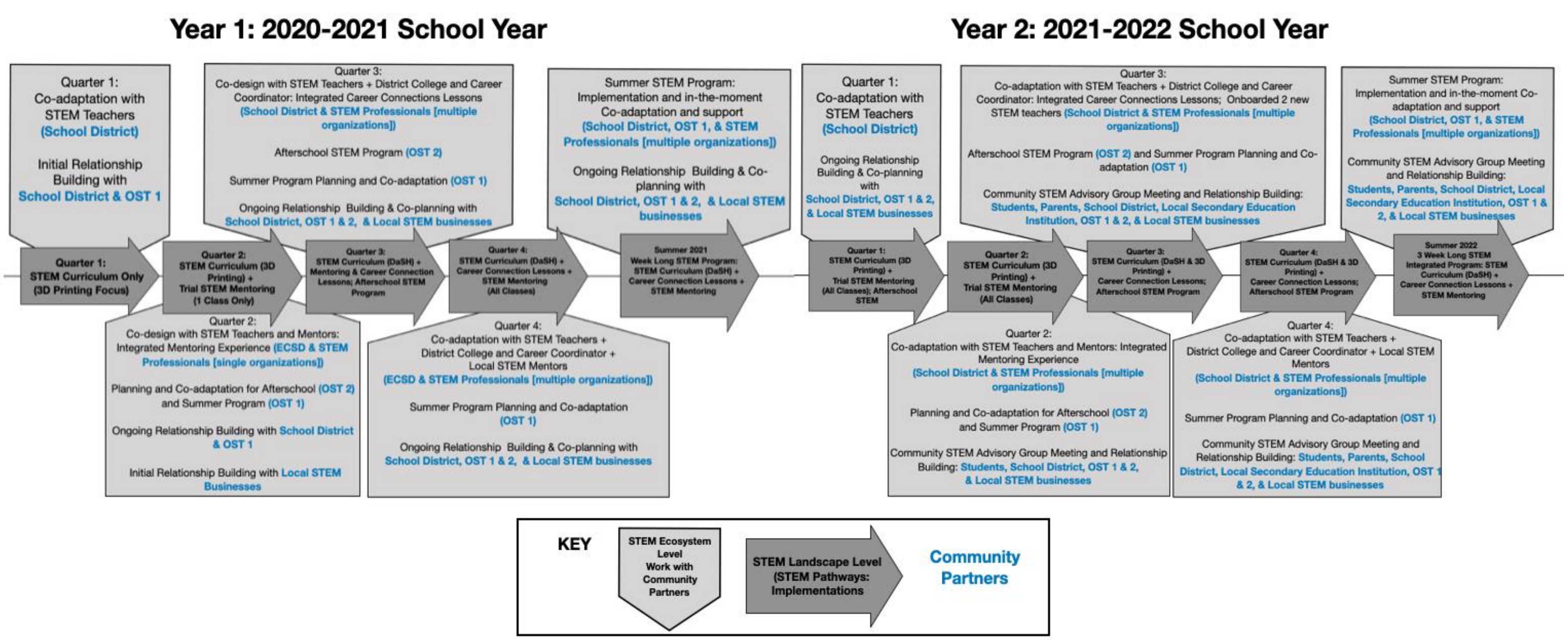
Partnership development takes time and must be viewed from a long-term lens. Developing relationships among community stakeholders, however time intensive, can result in strong collaborative partnerships. This project began with developing a previously established relationship with one of the OST organizations in the community (OST 1). Working with OST 1 served as a way into the community, and an opening to characterizing the STEM ecosystem d at the community level. It also supported us in developing a youth perspective on the STEM landscape, or opportunities and pathways. OST 1 was, and still is, one of the largest primary OST programming providers for youth in Mountain County. The organization did not, however, offer any STEM related programs. Leaders of OST1 hoped that our partnership would lead to the development of youth STEM programming of some kind. We originally planned to co-design summer STEM programming with OST 1 and work with OST 1 to identify and develop relationships with possible local STEM business partners. After developing the out-of-school STEM learning spaces, we envisioned partnering with the local school district to connect and integrate the core components of our model.

The COVID-19 pandemic made a summer program unlikely and created challenges in developing relationships with local businesses as they dealt with closures and other issues of their own. Therefore, the STEM summer program in the first year was not possible. OST 1 introduced our team to the Assistant Superintendent for the school district with whom we discussed integrating our project into middle school STEM classrooms. The Assistant Superintendent was enthusiastic about this opportunity and connected us with two middle school STEM teachers. Both teachers were excited about the opportunity to engage in co-designing, testing, and revising their STEM curriculum to include connections to local STEM occupations and STEM mentoring. As this new plan of action unfolded, we continued to work with OST 1 planning after-school programming and summer programming for the future. At this point, all the interactions were opportunity-based (see Figure 2).

Our team worked closely with the two STEM teachers, Eva and Sean (pseudonyms), whose weekly schedules included four days in-person (one-hour long session) with one day for asynchronous learning and lesson planning. Over the summer, we codesigned and adapted a 3D printing curriculum with Eva and Sean for use in their classrooms (Bhaduri et al., 2021b). The curriculum used storylining, an instructional design approach that uses students' questions to drive the lessons in ways that promote coherence, relevance, and meaning. Eva and Sean implemented this curriculum with their students in fall 2020. Each quarter, they worked with a new group of students who solved the question: "How can we support animals with physical disabilities so they can perform daily activities independently?" Students engaged in the engineering design process to develop and print prosthetic limbs for animals with disabilities using 3D modeling and printing. During quarters three and four in the spring of 2021, the research team worked with Eva and Sean to co-adapt and implement the sensor immersion unit which centered on students investigating programmable sensor systems called the Data and Sensor Hub (DaSH) (Chakarov et al., 2021), creating their own sensor data displays, and applying their knowledge of programmable sensors to local STEM problems and careers. We provided professional learning workshops, weekly group meetings between researchers and both teachers, and other as-needed support. Due to the ongoing COVID-19 pandemic, this professional learning had to be conducted entirely through remote, virtual contexts.

Figure 5

Ecosystem and Landscape Overview of a New STEM-Focused Rural Research Practice Partnership



In quarter two of fall 2020, we piloted an in-class mentoring approach where students received mentorship from a local medical research and treatment organization to embed connections between the curriculum and STEM careers. A low student-mentor ratio and working with students invested and interested in the interactions was essential for the organization to participate remotely. We found that student interest in STEM increased with the addition of the mentoring component (Bhaduri et al., 2021a).

In quarter three in the winter of 2021, the research team worked in collaboration with the school district's lead College and Career Counselor and Eva and Sean to develop and pilot a new curriculum that could be integrated into middle school students' STEM learning experiences. This curriculum focuses on developing youth's understanding of what STEM entails, how their coursework (e.g., 3D printing, programmable sensors) connected to STEM careers in their local community, and what local STEM career pathway opportunities existed. In quarter four, we support the implementation of all three components (Sensor Immersion, career connections, and mentoring curricula) into the two middle school STEM classes.

Through our relationships with the school district and OST 1, we discovered a second OST organization (OST 2) that offered STEM-focused programming in an after-school setting. The research team met with the director and program coordinator from OST 2 to discuss implementing a pilot after-school program that would adapt the sensor immersion curriculum, career connection lessons, and mentoring. OST 2 piloted the Sensor Immersion Unit and career connections at one site over five days. OST 2 leaders noted that the youth in this pilot implementation were highly engaged and interested in STEM. This began a relationship with OST 2 that has helped surface challenges previously unknown. We discovered that OST 1 and OST 2 had a longstanding and tenuous relationship as they were regularly competing for participants from the same communities. We organized a virtual meeting between the two organizations to discuss the possibility of creating connected STEM opportunities for youth that are built on each other. Both organizations were open to collaborating toward this purpose. This was the start of moving this partnership from an opportunity-based partnership toward a collaborative partnership (see Figure 2).

Our team continued to work with OST 1 to plan for the summer 2021 programming, a four-week summer camp where each week would have a different focus. Together, we planned a week-long STEM-focused learning experience designed to be inclusive, accessible, and engaging for all youth regardless of ability, home language, or experience level with programming. The week integrated the sensor immersion, career connections, and mentoring curricula into the summer camp context. This required a collaborative working relationship between OST 1 and our team to conduct training for the summer staff, recruit educators, recruit local STEM professionals to be youth mentors, and train the camp's high school-aged youth interns.

During the STEM week, youth learned how to build and program the DaSH, investigated STEM careers related to computing and sensor usage, and met with mentors three times. In these activities, participating youth brainstormed projects using the DaSH that could solve locally relevant problems such as: creating an early warning system to detect wildfires using temperature, soil moisture, and CO2 sensors; a wildlife fence system using a sound sensor to wildlife close to the road and alert motorists and local wildlife rangers; a system to find someone who is lost in the wilderness or in an avalanche; and creating a smart garden that uses sensors to monitor the environment and automatically control the moisture-level, temperature, and humidity.

After the STEM week, youth and staff were interviewed and provided feedback on the experience. The youth noted:

> "I loved the coding. I think it was a fun way to learn."
>
> "I liked the programming and getting to wire the sensors."
>
> "It's just cool to like, piece together stuff, puzzle it, make it kind of your own. And then for it to actually like, do something and work, it's really cool."
>
> "I feel like I learned a lot. It can be useful in the future for a STEM career. Like, I can think back to this or know how I programmed it."
>
> "I learned that a STEM job is really fun and you use a lot of technology."

During the interviews, the summer camp staff noted:

> "Watching the kids present their projects at the end of the week was a highlight. Getting to see how much they learned."
>
> "The entire class created a video to showcase their project about a system that could tell you when a class is being too loud for the library. It was cool seeing the whole class come together to work on that."
>
> "The enrichment activities were really fun and engaged the kids and connected back to the programming."
>
> "I think kids will notice sensors in the real world more, I know I have."
>
> "They are going to take away that they can do this [coding and wiring] and that they were able to figure it out."
>
> "As the week went on the kids got more and more engaged."
>
> "I had kids who I thought would be challenging gain confidence in themselves and their abilities."

Through the planning and implementation of the STEM week of summer camp, we also improved our partnership with OST1 and established additional relationships with local STEM professionals. Based on this feedback, OST 1 and the research team are working to fully integrate STEM learning experiences across the entire upcoming 2022 summer camp. This experience exemplifies the possibilities when partners and stakeholders see and experience the value of providing rich ongoing STEM experiences for youth in their community. It can lead to increased partner engagement and commitment and the development of more shared partnership goals.

Year 2

We are currently still in year 2 of the partnership and are here reporting on the ongoing developments thus far. In year 2, we expanded the STEM programming offered by OST 2 and the STEM classes offered at the middle schools within the partnering district. Working with the local school district, two additional middle school STEM teachers joined the project, extending the student impact of the partnership. We are continuing to work with the college and career counselors and coordinators to refine the career connection lessons integrated directly into youth STEM learning experiences to make explicit connections between their STEM experiences and local STEM careers and career pathways. Through the partnership with the school district the assistant superintendent introduced us to the two district education technology specialists, with who we have been collaborating closely within the work with the middle school STEM teachers and have together worked toward the goal of building capacity in the district to support teacher implementation of project related curricula and STEM mentoring experiences.

The partnership has been able to bring together OST 1 and OST 2 to coordinate STEM learning opportunities between after-school and summer programming. OST has been collaborating with the research team and local STEM businesses to plan for a three-week-long summer camp with fully integrated STEM components such as the DaSH, STEM mentoring with local STEM professionals and businesses, and explicit career pathway connections. OST 2 has since expanded their STEM learning programming to follow a storyline format, integrate STEM career pathway learning opportunities, and utilize local STEM businesses for STEM mentorship and STEM learning opportunities at sites outside of the after-school program.

Additionally, through the direct collaboration with the individuals in the school district, OST 1, and OST 2 we have been able to develop new relationships across the STEM ecosystem leading to the formation of a STEM community advisory group bringing together multiple stakeholders within the community including individuals from the school district, OST 1, OST 2, parents, students, community leaders, and multiple local businesses and STEM professionals, some who have served as STEM mentors and some who are participating in the partnership for the first time. This group is working to better understand the local rural STEM ecosystem and support existing STEM pathway opportunities and identify opportunities to develop new STEM pathways that traverse the entire STEM ecosystem. This points to the partnership becoming a more collaborative partnership and possibly moving toward an interconnected partnership (see Figure 2).

RQ2: Tools and Practices to Support Rural STEM Pathways for Youth

As a result of the collaborative work of the partnership, multiple tools and practices have been developed and utilized to cultivate the relationships between community stakeholders participating in the partnership. These tools and practices are described below.

STEM Pathway Development Tools

Several STEM pathways development tools emerged from our initial years of the RPP. These tools include the following components:

1. **Survey of the existing STEM ecosystem.** We realized that it is crucial to identify who is already providing STEM experiences for students in the community (i.e., informal science organizations, and businesses that engage in outreach). We aim to create STEM experiences valuable to rural youth, the local community, and our research team. The team worked with community members to develop an initial Community Asset Map to depict the existing STEM ecosystem. It would enable youth to realize the STEM opportunities available and help define their STEM pathways.
2. **Co-designed Curricula and Career Connections Lesson Activities**. The co-designed curricula and Career Connections lesson activities include 1) iteratively refined in-school and OST curricula built around focal phenomena and integrating place-based sensor-integrated and 3D printing activities, and 2) guides to help facilitators and mentors from

local businesses support youth in these learning activities. The 3D printing curriculum focused on using 3D design, 3D printing, and augmented reality to design prosthetics for disabled animals. The sensor immersion curriculum focused on youth investigating programmable sensor systems, creating their own sensor data displays, and applying their knowledge of programmable sensors to local STEM problems and careers. The professional development had to be conducted completely through remote, virtual contexts due to the pandemic. Our team provides professional learning workshops, and ongoing professional development through just-in-time meetings as needed to support the teachers, mentors, and other partner organizations. Toward this effort, our team has worked to revise and refine STEM curricula and STEM career activities for both in-school, afterschool, and summer camp contexts, and support the adaptation of the curricula for either in-person or remote learning.

3. **Newsletter for ongoing communication between partners.** The research team along with input from the school district, and both OST partners compiled two newsletters during year 1 of the partnership. The goal is to disseminate our project updates through these newsletters to participating organizations/individuals and members of the local community. In spring 2021, the first newsletter included our project accomplishments and thanked every individual who participated, volunteered, and supported the goals of the partnership activities. During the 2020-2021 school year, we shared how students, teachers, and organizations within the county came together intending to increase youth knowledge, interest, and engagement with STEM career pathways. Through the work of these partners, more than 700 middle school students had the opportunity to engage in STEM and computing learning experiences, connect to STEM careers in both their local community and the wider world, and integrate mentoring experiences with STEM professionals.
4. The fall 2021 newsletter included highlights from summer and fall 2021 and future project goals. We shared how over 120 youth met with local STEM mentors in the summer camp. They investigated local phenomena using their individually programmed sensor systems and learned about STEM career pathways. There were other highlights from the fall 2021 implementation of the 3D printing unit and how different guest speakers and mentors interacted with participating students to support their animal prosthetics design. We also presented updates from our first STEM community partnership meeting and our plans to continue to meet and bring community members together. The newsletter, developed collaboratively with partners and stakeholders, has served to keep partners and community members informed and engaged in the project as there are many components to the partnership and not all stakeholders are directly involved in every component. Partners have also shared the newsletter with the youth and parents they serve to increase community engagement and excitement for STEM opportunities being developed and offered in the community.

STEM Pathway Development Practices

We identified the following key practices crucial for developing STEM pathways for rural youth by involving local community partners.

1. **Laying the foundation for community partnerships.** It is essential to clarify the goals and capacities of each partner in the RPP involved in developing the STEM pathways. We created a one-page document to define the rural STEM Pathway development innovation goal, directed to the partnership audience. Furthermore, we learned about the partner's work/goals and shared goals and identified alignments between the partner's goals and our project goals to create mutually beneficial relationships. We provided as many details about the ask for involvement as possible. Our team set up a communication structure to determine the point of contact, mode, and frequency of check-ins, and ways to share existing resources developed to serve our targeted rural community. Furthermore, we identified potential partnerships organizations and partners to serve as STEM mentors. We reached out to likely partnership organizations/individuals our teachers have already had positive outreach experiences. We asked school leadership, teachers, etc., to make first introductions between our project and contacts they have worked with successfully before. This formed the foundation for the community partnership and the gradual development of youth STEM pathways.
2. **Building community partnerships.** After, the initial foundation of the partnership **building**, we engaged partners in activities that best suited their individual and organizational goals. Our team created a program that works for all participating organizations by determining their needs. These often-included scheduling needs, language supports, programming opportunities for all youth. We also noted the needs of the mentor organization, like having a small student-mentor ratio, working with an engaged student audience, minimizing time and impact on their workday. Then, we implemented different structures for student-mentor experiences based on the setting. For example, during virtual mentor meetings, we required more organization: agendas, tips for engaging with middle schoolers, preparing students for mentor meetings, e.g., preparing questions in advance, preparing to share updates on their classwork. But when meeting in person/during summer, many of these supports seemed too rigid and unnecessary. Our team also realized the necessity to find opportunities for the partners to provide support. STEM professionals can support youth with curriculum projects, share related career experiences often tying back to the community, provide access to stories and resources related to topics of interest to the students, and correspond via email with students. We realized it was important to offer ways for partners (teachers, mentors, etc.) to share ongoing reflections before and during the implementation and ideas for co-development of activities. From the data collected, our partners reflected on how they appreciated constant communication and regular project updates. Most of them were excited to continue being involved with the project to support the bigger goal that the RPP was working towards.

Discussion

This project is continuing to work toward generating theory, resources, and research data on how to develop collaborative rural community partnerships and support teachers and OST facilitators to provide effective and engaging STEM learning experiences. These experiences emphasize relevant opportunities for diverse students to make connections to and generate interest in local STEM careers and career pathways within the STEM ecosystem in Mountain County. Developing community partnerships has revealed some long-standing issues between two of the OST programs within the context of the small rural community. The project has impacted these after-school programs in a positive and constructive way through intentional communications and a renewed spirit of cooperation. Hence, in such developing RPPs there always arises a need for bridging and buffering between partners. This involves facilitating the connection between partner organizations and creating protective spaces for those working in the partnership to keep possible contradictory guidance, policy, or leadership at bay.

Furthermore, from this developing design-based RPP we gathered that partnership building takes time, and commitment from stakeholders occurs when they see value in the partnership and the resulting STEM pathway opportunities (Coburn et al., 2013). We noticed that partner organizations and individuals find this partnership to give back to their community. For instance, a handful of the STEM professionals/mentors grew up and did their schooling in the local community and went outside this Mountain County for future STEM college degrees. On completion of their degree, they returned to the community and found a way to give back to the community by sharing their experiences with youth and encouraging them to realize the opportunities available in their community. They are also actively involved in supporting us brainstorm ways to develop other possibilities for the local youth. This allows for accessing the local resources to identify and develop the STEM Ecosystem and eventually STEM Landscape for the future generation of youth in the community.

This work also enabled us to realize the need to tap into and build on the relationships and contacts of the local stakeholders. It is especially important in a rural context where most of the stakeholders know each other and what is going on in the community. During the initial partnership building process, it is vital to identify potential partnerships organizations and partners to serve as STEM mentors, focusing on relevant and achievable goals for the partnership. It allows stakeholders to see progress and move forward together as a collaborative team and contributes to a “niche” reform rather than large-scale reforms (Yurkofsky et al., 2020). There can be instances when potential partners we contacted do not get back, but we should not get discouraged from reaching out to these partners or continuing the efforts of developing STEM opportunities and access for underserved youth.

Conclusion and Implications

This article presents the benefits and challenges of developing a rural design-based Research Practice Partnership (RPP) to create STEM opportunities and access for youth in the local STEM Ecosystem. It presents through the process of co-design with local stakeholders, the RPP was able to stitch together various learning experiences (i.e., career connection lessons, STEM mentoring, and STEM focused curricula) to create opportunities for students to explore local STEM Careers and career pathways. This RPP utilized the existing STEM ecosystem and identified ways to turn it from opportunity-based to a more collaborative and eventually interconnected ecosystem. The paper also presented that co-design can be one strategy for creating opportunities for rural youth to engage with STEM in ways that are specific to their communities. This paper describes the use of co-design to develop opportunities for youth in rural communities to engage with STEM. These findings outline contributions to youth STEM engagement and awareness of STEM career pathways and opportunities. It also highlights the power of co-design with multiple stakeholders and partners in helping to develop local capacity and develop RPP relationships. While these findings worked for Mountain County, we believe that the RPP needs to be studied further to be able to generalize to other communities.

Two possible future directions of work identified through this work include the need for sustaining the partnerships and including families as part of developing pathways. To this point, it has been difficult to involve parents directly in the partnership due to challenges related to the COVID-19 pandemic. Currently, two parents have been invited to participate in the project community STEM advisory group. Moving forward, the project is working to involve more parents and caregivers directly in project planning and activities.

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Appendix

A1. Guiding questions and Key Construct for the Reflective Memo:

Guiding questions:

1. How has our work centered the problem of developing powerful learning experiences for youth (in and out of school) that ignite interest in STEM and computing and develop career connections?
2. What kinds of local partnerships can make that more of a possibility? (Penuel et al., 2020).

The **key constructs** involved in these memos are

1) Bridging: facilitating connections with initiatives and other operating parts of the partner organizations.

2) Buffering: creating protective spaces for those working in the project that keeps possible contradictory guidance, policy, or leadership at bay.

3) Shared tools involve development of tools used for asynchronous, ongoing collaboration, including capturing decisions and feedback for improvement. (Yurkofsky et al., 2020)

4) Informal support: Ongoing work that helps partners as they implement youth learning experiences that are not captured in other representations of the partnership. Ex. Helping with a technological issue.

About the Authors

Srinjita Bhaduri is Research Scientist at the Institute of Cognitive Science at the University of Colorado Boulder. She engages in interdisciplinary research in Human-Centered Computing, Maker Technologies, and Learning Sciences. Dr. Bhaduri explores learning environments to support underserved children in their investigation of maker technologies, particularly programmable sensor technology and 3D printing, in a personally meaningful way. She believes every child should be able to utilize their funds of knowledge and solve real-world problems by leveraging maker technologies to become the future generation of creators.

Quentin Biddy is Assistant Research Professor in the Institute of Cognitive Science, University of Colorado Boulder. He is researching and developing open source resources to support high school and middle school science teachers transitioning to phenomena-driven, three-dimensional learning and assessment aligned to the NGSS while integrating computational thinking using the DaSH, a programmable Data Sensor Hub. Through this work, he is focusing on supporting middle school science teachers intentionally integrating Computational Thinking Practices into students' learning experiences through co-designed CT integrated NGSS aligned storylines. His research/work experience and interests focus on effective science learning and teaching, phenomena-driven learning, NGSS aligned 3D Learning and formative assessment, CT integration, Pedagogical Content Knowledge, teacher professional learning, and the Nature of Science and History of Science in science education.

Colin Hennessy Elliott is Research Scientist at the Institute of Cognitive Science at the University of Colorado Boulder. His research is focused on bringing a critical eye to STEM learning and the implications for teaching. He uses his experience working with youth to guide his research foci, studying the STEM education landscape with a focus on educational justice. He has expertise in video-based ethnographic methods, particularly Interaction Analysis and ethnomethodology, and participatory research methods. He believes it is important to explicitly carve out space for youth and participating adults to collaborate in STEM education research.

Jennifer Jacobs is Associate Research Professor at the Institute of Cognitive Science, University of Colorado Boulder. Her primary research interests are in classroom teaching, teacher and student learning, and teacher professional development. Most recently, Dr. Jacobs has helped to develop and study the impact of two mathematics professional development programs, both supported by the National Science Foundation.

Melissa Rummel is an educational Designer and educational resource developer and PD Instructor at the UCAR Center for Science Education. Melissa develops educational content for the Learning Zone website, exhibits, and K-12 curriculum focused on Earth Systems Science and NGSS. She also develops and facilitates STEM education professional development for K-12 teachers.

John Ristvey is the Director for the UCAR Center for Science Education. He provides expertise in Out of School Time (OST) programming with student supports and STEM education. Ristvey coordinates each of the teams and lead the design team as well as the work of the advisory board. He has conducted extensive research and development work in STEM OST projects such as Cosmic Chemistry (Institute for Educational Sciences, Department of Education) and NanoExperiences. Ristvey was the PI for three NSF-funded projects: NanoLeap, NanoTeach and NanoExperiences. He also was the lead developer for the Dynamic Design series of engineering modules for NASA's Genesis mission. He holds a Master's degree in Secondary Science Education from University of Houston, Clear Lake, TX.

Tammy Sumner is a Professor at the University of Colorado, with a joint appointment between the Institute of Cognitive Science and the Department of Computer Science. She is currently serving as the Director of the Institute of Cognitive Science. She leads an interdisciplinary research and development lab that studies how computational tools –combining cognitive science, machine intelligence, and interactive media–can

improve teaching practice, learning outcomes and learner engagement. Her research and teaching interests include personalized learning, learning analytics, cyberlearning environments, educational digital libraries, scholarly communications, human-centered computing, and interdisciplinary research methods for studying cognition.

Mimi Recker is a Professor of Instructional Technology & Learning Sciences at Utah State University. Mimi earned a bachelor's degree in mathematics from the University of Pennsylvania, and after working for several years as a software engineer in Silicon Valley, she earned her PhD from the University of California, Berkeley. Mimi has held academic positions at the Georgia Institute of Technology, and at Victoria University of Wellington in New Zealand. Mimi began her faculty appointment at USU in 1998 and served as Department Head from 2008-2015. Her research focuses on helping educators and students reap the benefits of cyber-learning through access to the network of high-quality, interactive and free online learning resources. Over the years, this line of research, largely funded by the National Science Foundation, has involved a dynamic mix of faculty, post-doctoral students, and graduate students from Utah State University, as well as from around the world.

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Integrating Computational Thinking in Rural Middle School Art Classes in Eastern North Carolina

R. Martin Reardon, *East Carolina University*

With funding from a National Science Foundation (NSF) grant, an innovative endeavor to integrate computational thinking into the teaching of both music and visual arts in three rural school districts in North Carolina was launched in early December 2018. Over the next five years—a time span that encompassed a major hurricane that devastated the area and the COVID-19 pandemic—the partners in a research practitioner partnership collaborated to create and refine curricular activity system projects in both subject areas. This paper is focused on the visual arts component of the grant activities. After discussing the genesis of the project, I situate it as contributing to the cultural capital of the middle school student participants and situate it theoretically in cognitive flexibility theory. I then discuss the operational definition of computational thinking that underpinned the design of the elements of the curricular activity system, which were then refined and adapted to the rural contexts in collaboration with the teachers. I provide an overview of the curricular activities (a professional development website was created by grant colleagues at the Friday Institute at North Carolina State University) and discuss students' perspectives on the concepts and approaches of computational thinking. I close with reflections on the importance of the project.

***Keywords*:** rural education, computational thinking, visual arts, music, integration

Computational thinking is arguably more readily associated with the study of science, technology, engineering, and mathematics (STEM) than with its later extension into the study of the arts (STEAM). In his groundbreaking *Mindstorms* project, Papert (1980) sowed the seeds of computational thinking by inviting children to encounter the powerful ideas that underpinned the human/computer interface. Papert conjectured that doing so would prepare them for the work environment of the future. In his foreword to the second edition of *Mindstorms* (1993), Sculley—who retired in May 1993 after 10 highly successful years as the Chief Executive Officer of Apple—praised Papert for being the premier leader in the education reform movement—one who understood that “technology in education is effective only if placed in a larger context” (p. vii).

The larger context for the grant project that is the focus of this paper was a collaboration among faculty at East Carolina University and representatives of three rural school districts in eastern North Carolina who were members of a research practitioner partnership, hereafter referred to as RPP. (Coburn et al., 2013; Coburn & Penuel, 2016). RPPs were defined by Coburn et al. (2013) as “long-term collaborations between practitioners and researchers that are organized to investigate problems of practice and solutions for improving schools and school districts” (p. 1). Even though the grant submission was oriented to enriching the educational environment in the schools rather than addressing a problem of practice, with the enthusiastic support of my East Carolina University colleague who had inaugurated the RPP, representatives from the three districts reviewed a draft of the grant document prior to convening to formally discuss its submission.

This initial meeting was notable for its cordiality even as it immediately engaged us with joint work at the boundaries (Penuel et al., 2015). Although the draft submission was oriented to science and mathematics (in response to a call for proposals issued under the umbrella of the Computer Science for All initiative), the three district representatives had independently conceived of the potential benefits of the grant in their social worlds in the teaching of visual arts and music. Our school district partners were acutely aware of the challenge that their perspective on the grant represented, but their focus on visual arts (two school districts) and music remained firm. Despite some foreboding related to the likelihood of an arts-based proposal being funded under the Computer Science for All initiative, we pivoted the focus of the grant to its new cultural orientation and flagged sections of the draft for rewriting. We settled on "iCS4All" as our abbreviation of "Integrating Computer Science and Computational Thinking in Visual Arts and Music in Three Rural Eastern North Carolina School Districts."

Theoretical Framework and Context

Rural places thrive as their own complex, rich, and dynamic social worlds. They are collectively neither "a kind of safety deposit box that stores America's fundamental values" (Lichter & Brown, 2011, p. 568) nor merely pantries and bedrooms for urban areas. Bourdieu (1986) referred to social worlds as consisting of "accumulated history" (p. 241) that, by synthesizing otherwise distinct elements of the context, constituted a form of capital that enables "agents or groups of agents . . . to appropriate social energy" (p. 241). The accumulated history of eastern North Carolina—the location of iCS4All—is inextricably intertwined with two technological innovations. The first was the purportedly accidental discovery in 1839 of the flue-curing process for tobacco (Biles, 2007). This innovation yielded a bright leaf tobacco and fueled a financial boom that enriched the 11 counties in the "Old Bright Belt" for generations (Biles, 2007, p. 158). The second innovation was the cigarette rolling machine used by W. Duke, Sons and Company—starting in the mid-1870s—to produce up to 120,000 cigarettes per day and dominate the market (Denton, 2019).

Both these innovations impacted what Bourdieu (1986) conceptualized as economic capital (assets convertible into money and institutionalized in property rights). The social world that was founded on the economic capital of tobacco-based prosperity in the Old Bright Belt began to change following the 1964 Surgeon General's report that cited the health risks associated with smoking; formerly thriving tobacco-based communities encountered financial hardship and their populations dwindled as their economic capital dried up.

According to Bourdieu (1986), economic capital can be converted—with concerted effort—into cultural capital (institutionalized in educational qualifications). Bourdieu (1977) defined cultural capital as "instruments for the appropriation of symbolic wealth socially designated as worthy of being sought and possessed" (p. 488). Of particular interest in the context of iCS4All is Bourdieu's (1979) division of cultural capital into *incorporated* cultural capital ("an individual's inherent and lasting disposition influenced by processes of formal education and individual socialization" [Sieben & Lechner, 2019, p. 1]), *institutionalized* cultural capital (entailing institutional titles), and *objectified* cultural capital ("tangible cultural goods such as books or works of art that can, in contrast to incorporated cultural capital, be physically transferred" [Siben & Lechner, 2019, pp. 1-2]).

The iCS4All endeavor was directly oriented to impacting students' inherent and lasting dispositions towards art—their incorporated cultural capital—which DiMaggio (1982; DiMaggio & Mohr, 1985) characterized as "children's exposure to cultural forms such as classical music, great works of literature, the arts, galleries, and museums" (Davies & Rizk, 2018, p. 338). The aim of iCS4All was to engage middle school students in the participating rural school districts with an enriched perspective on art through integrating technology-enabled computational thinking into their curriculum. Specifically, the aim was to integrate the concepts and approaches of an appropriate definition of computational thinking—knowledge "worthy of being sought and possessed" (Bourdieu, 1977, p. 488) because it may provide access to economic capital in the "Age of Digital Information" (Linn, 2010, p. vii)—with the creation of objectified cultural capital in the form of works of art.

Curriculum Integration and Cognitive Flexibility

Our integrative approach aligned with cognitive flexibility theory as discussed by Efland (2002) in the context of art education. Efland critiqued a symbol-processing computer analogy to the acquisition of knowledge—an analogy that might seem to be the most obvious choice in our case—as pertinent to computer science but of limited relevance in art. As Efland and the exponents of cognitive flexibility theory highlighted, some learners who are adept at acquiring knowledge in conventional instructional contexts (e.g., medical students in early stages of their education or art students) struggle when they endeavor to apply that knowledge in real-world contexts—in "complex and ill-structured domains" (p. 83). Efland conjectured that, if learners possessed cognitive flexibility—simply defined as "a quality of mind that enables learners to use their knowledge in relevant ways in real-world situations" (p. 82)—they would have little difficulty putting their knowledge into practice.

Efland (2002) sourced the roots of cognitive flexibility theory in the work of a group of psychologists (e.g., Spiro, Feltovich, Coulson, and Anderson, among others) who studied the very difficulties experienced by medical students cited above. Well prior to the work of Efland and those researchers, however, in *The Psychology of Art*, Vygotsky (1971), but written some 40 years prior to 1971, addressed the question of what transforms a human contrivance into a work of art. In Leontiev's (1971) introduction to *The Psychology of Art*, he made a particularly apposite observation in the context of iCS4All: "Transformation into a figure or symbol does not of itself create a work of art. The 'pictographic quality' of a production and its quality as a work of art are two very different things" (p. vii). Our integration of computational thinking into the visual arts classes was not oriented to the carrying out of a set of disengaged steps but to students' appreciation of the affordances of the technology in facilitating their intention. We were oriented to engaging students in that "metamorphosis of [their] feelings" (Leontiev, 1971, p. vii) that distinguishes works of art from pictographs.

Operational Definition of Computational Thinking

Shortly after Wing (2006) characterized computational thinking as "a universally applicable attitude and skill set" (p. 33) in her three-page article published by the Association of Computer Machinery, the National Research Council (NRC, 2010) featured Sussman's depiction of "computational thinking-as-basic-language" (p. 15) among many other conceptualizations. Grover and Pea (2013) wryly remarked that the multiple conceptualizations of computational thinking at the NRC workshop the very diversity "threw into sharp relief the lack of consensus that seems to have bedeviled this space" (p. 39).

To facilitate the implementation of iCS4All, my colleagues and I sought a definition that was oriented to computational thinking-as-basic-language while offering a clear path to operationalization. We found such a definition in a conceptualization of computational thinkers as well versed with the concepts of logic, evaluation, algorithms, patterns, decomposition, and abstraction and skilled enactors of the processes of tinkering, creating, debugging, persevering, and collaborating (*Barefoot*, 2020). The *Barefoot* (2020) initiative was set up in the United Kingdom in 2014 to empower "primary school teachers in the UK to deliver the computing curriculum brilliantly with free workshops, helpful online guides and engaging lessons" (https://www.barefootcomputing.org/about-barefoot, para. 1). Despite the intentional orientation of the *Barefoot* definition to younger children, as shown in Table 1, the concepts and processes are relevant far beyond the age of younger children, and the alignment of the components of the definition with the conceptualization of computational thinking-as-basic-language is apparent.

Implementation

The plan for iCS4All was that I would lead the creation and collaborative refinement of some eight or so approximately month-long extended curricular activities (Reardon & Webb, 2019) and share these with the teachers for them to implement—adjusting them as appropriate. In putting the plan into action, one or both of my colleagues from the East Carolina University computer science department who were involved with iCS4All and at least one of the graduate assistants working on it drove with me monthly to visit with all three of the teachers who gathered at one of the schools on a rotating basis. I referred to these meetings as Moderation Meetings since the idea was for them to bring student work with them to illustrate the viability of the activities as designed or as they had moderated them. Those in-person meetings were crucial to the implementation of the grant.

The teachers filtered each curricular activity through their intimate knowledge of the local community and what would "work" in the environment in which their students thrived. The following anecdote illustrates how easily our assumptions from our East Carolina University perspective could be jarring in the local context.

When I picked-up the rental car for the almost two-hour drive for our first visit to one of the school sites, I was taken aback to be given the keys to a brand-new, bright yellow sports car with a very loud exhaust. (At that time, East Carolina University had an agreement with a car rental firm for faculty travel.) I pleaded for something a little less conspicuous, but there was no other car available.

Table 1

Components of Computational Thinking

Concepts		Processes	
Logic (predicting and analyzing)	Logic helps us to establish and check facts and make predictions.	Tinkering (experimenting and playing)	Tinkering means trying things out through experimentation.
Algorithms (making steps and rules)	An algorithm is a precise sequence of instructions, or set of rules, for performing a task.	Creating (designing and making)	Creating is about planning, making, and evaluating things (e.g., animations, games, or robots).
Decomposition (breaking down into parts)	Decomposition is breaking a problem or system down into its parts.	Debugging (finding and fixing errors)	Debugging is about finding out what is wrong in an algorithm or program and fixing it.
Patterns (spotting and using similarities)	By spotting patterns, we can make predictions, create rules, and solve other problems.	Persevering (keeping going)	Persevering is never giving up, being determined, resilient, and tenacious.
Abstraction (removing unnecessary detail)	Abstraction is identifying what is important and leaving out detail we do not need.	Collaborating (working together)	Collaborating means working with others to ensure the best result.
Evaluation (making judgment)	We use evaluation when we make judgements based on different factors, such as design criteria and user needs.		

Note. Table 1 reformatted from the explanation of the terms in the *Barefoot* classroom poster available at https://www.barefootcomputing.org/docs/default-source/default-document-library/cas-computational-thinking-key-term-cards.pdf?sfvrsn=942592ea_0

When we arrived at the school—closely abutting the county highway on the outskirts of the nearby town and directly across from an extensive corn field—I was disconcerted to see the entry to the visitor's parking directly off that county highway blocked by several large traffic cones. Obviously, there must be another entry further down the highway, I reasoned. After I turned in, however, I realized it was the bus entry and gave access to the back of the school building. I made a sedate turn, hoping that the thrumming growl of the sports car's engine would not distract too many students in the adjacent classrooms, and drove back onto the county highway. At that stage, my companion suggested that he should move the cones so I could drive in through the obvious entry. While he replaced the cones, I parked the car in one of the visitor's spots. We reported to the front office to find that we had triggered a trespass alert to the sheriff's office! We clearly were not "locals" because "everybody" knew that the (completely unmarked) entry into the visitor's parking involved turning off the county highway just before the adjacent church building and driving down the access lane behind it.

Grant Details

As discussed above, we named the National Science Foundation grant (No. 1738767) that funded our project "Integrating Computer Science and Computational Thinking in Visual Arts and Music in Three Rural Eastern North Carolina School Districts" (iCS4All) toward the end of the initial meeting with the representatives from our RPP partners. Mindful of the warning issued by Roschelle et al. (2010) that "new technologies must address the core curriculum or face certain marginalization" (p. 239), we integrated the components of our visual arts curricular activity system projects with the participating teachers' implementations of the North Carolina Essential Standards Visual Arts Eighth Grade—especially the standards that address visual literacy (8.V.1–8.V.3; https://bit.ly/3m8wxSM).

We intended that the students would continue to develop the digital literacy they had already acquired during their elementary school years in the participating districts (Spires & Bartlett, 2012). In addition, through their teachers' participation in the professional development and ongoing support that we provided as part of iCS4All, we intended that the students would develop enriched understandings of the subject matter by virtue of their teachers' integration of the concepts and approaches of computational thinking into their classes. Lastly, we intended that the principals of the two schools and the students' parents would be invited to engage with appropriate elements of the curricular activity system components and contribute to their refinement. Our overarching research question was: To what extent can computational thinking be integrated with visual arts teachers' customary teaching practice and be inculcated by their students?

Curricular Activity System Components

With substantial input from one of the art teachers and two graduate assistants, we developed and refined 12 curricular activities, as shown in Table 2. The computational thinking concepts/approaches (see Table 1) that were the main foci of each activity (listed roughly in order of priority) are listed in the third column together with the non-standard materials (including technological software/hardware) that our students used. (A wide range of non-standard materials could be used instead of those listed—particularly technological software/hardware.) The activities are not inherently sequential, but the later activities are more demanding, and it would seem best to maintain the first and last activities as "bookends."

Table 2

Curricular Activities for Visual Arts

Title	Description	Concepts (C) Approaches(A) Materials (M)
Introducing Computational Thinking in the Art Room	An introduction to computational thinking terms.	C: Logic, Patterns A: Tinkering, Persevering, Collaborating M: Dollar Store-type puzzles (~25-50 pieces), CoSpaces
Kandinsky: Elements of Art & Principles of Organization	Create cut paper designs inspired by Wassily Kandinsky and then analyze them according to the elements of art and principles of organization	C: Algorithms, Decomposition, Evaluation, Abstraction A: Tinkering, Debugging, Creating, Persevering M: Adobe Fresco
Ready, Set, Go	Explore pattern recognition and create their own game puzzle.	C: Algorithms, Patterns A: Tinkering, Collaborating, Persevering, Creating M: Chromebooks, Google Draw, http://www.setgame.com/set/puzzle
Symbolic Portraits	Create a self-portrait layered with symbolic imagery	C: Algorithms A: Creating M: Personal cell phones, Printer, CoSpaces
Layers of Meaning: Palimpsests	Learn about palimpsests and use the idea of layering on a musical score as a canvas by embedding symbols in the score using color and line.	C: Algorithms, Logic, Patterns, Evaluation A: Creating M: Cricut, Printer
Digital Mondrian	Transform an image from Realism to Abstraction using software.	C: Abstraction, Decomposition A: Creating, Debugging M: Chromebooks, Google Draw, Printer
Graffiti & Contemporary Street Art	Explore typography, graffiti and contemporary street art and create their own personalized messages.	C: Algorithms, Decomposition, Patterns, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: Adobe Fresco, Wide-Format Printer

Title	Description	Concepts (C) Approaches(A) Materials (M)
Photography	Study work of famous photographers to uncover what creates a compelling photographic image then create their own photographs, documenting their world.	C: Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering M: iPads/Personal cell phones, Picture editing apps (e.g., Distress FX), Printer
I Am From . . . Sights of Home	Create a mixed media portrait of where they are from.	C: Decomposition, Patterns, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: Maps, Yarn, Needles, iPads, Printer
Moving Pictures & Claymation	Learn about the history of film then develop their own animated films using clay models.	C: Logic, Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: iPads, CoSpaces
Tactile Picture Books	Create 3D images based on children's stories and assemble into a tactile picture book that could aid a person who is visually impaired.	C: Logic, Algorithms, Decomposition, Abstraction, Evaluation A: Tinkering, Creating, Debugging, Persevering, Collaborating M: iPads, Tinkercad, Thingiverse, 3D Printer
Culminating Activity: Personal Visual Arts Portfolio	Compose and narrate a personal portfolio of curricular activity artifacts.	C: Logic A: Persevering M: iPads, CoSpaces

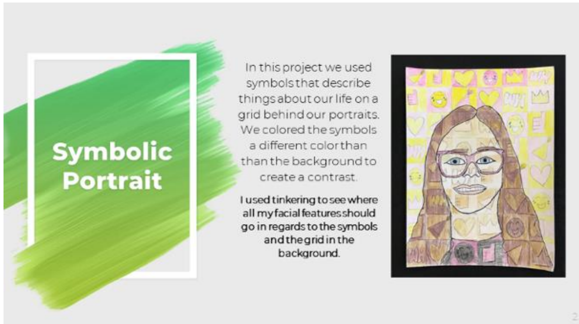
Note. A professional development website for teachers who are interested in pursuing the integration that iCS4All explored is on the PLACE website (see "iCS4All Art" and "iCS4All Music" at https://place.fi.ncsu.edu/) maintained at North Carolina State University.

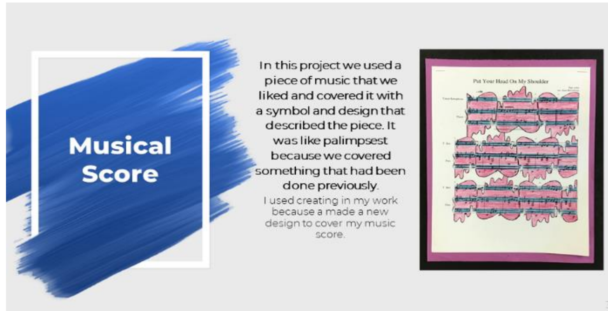
Evidence of Effectiveness

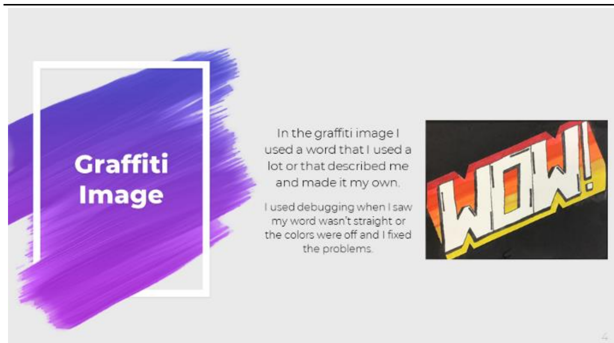
An early decision that we and the teachers agreed upon was that we were not intending to assess the accuracy of students' recitation of the contents of the definition of computational thinking. Whenever the students saw the key words, they also saw the thumbnail definitions of them. However, as shown in Table 2, the introductory curricular activity was designed to engage students with each of the six concepts and increase their awareness of the relevance of the five approaches to their learning of art as well as to their other school subjects. Our intention was to demystify otherwise arcane terms such as "algorithm" (referred to by one of the teachers as "a daunting term"). We assessed the effectiveness of the students' grasp of the concepts of computational thinking (see Table 1) by their reflections on their artwork and by gaining insight into their understanding of the six concepts by conducting focus groups. As shown in Table 2, the culminating activity was for the students to construct a portfolio of their work over the course of the year. Table 3 shows the artwork of eight projects from one student and her reflections on each project.

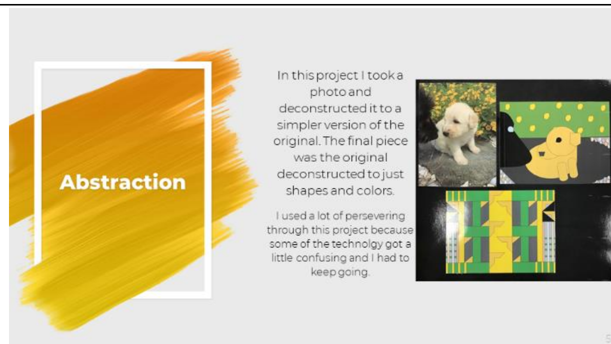
Table 3

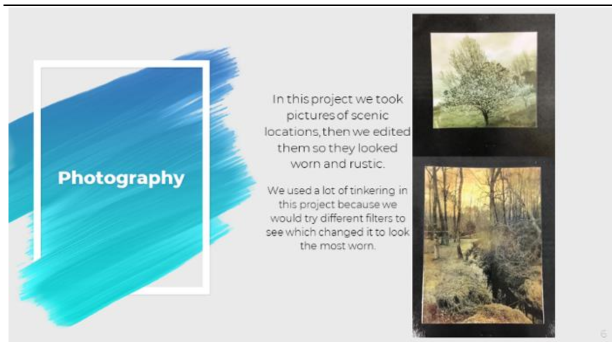
Project Portfolio

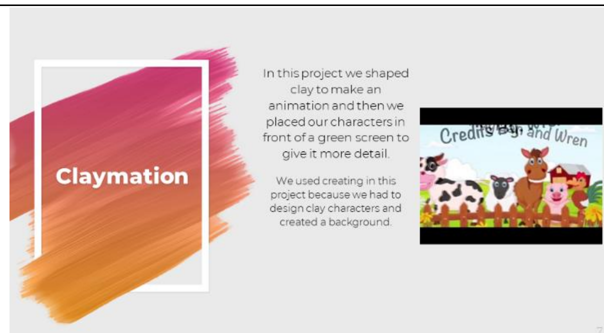


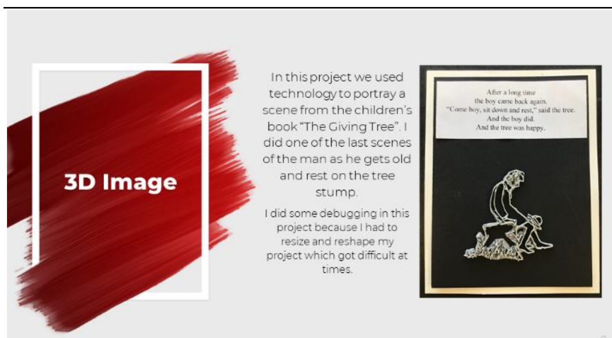


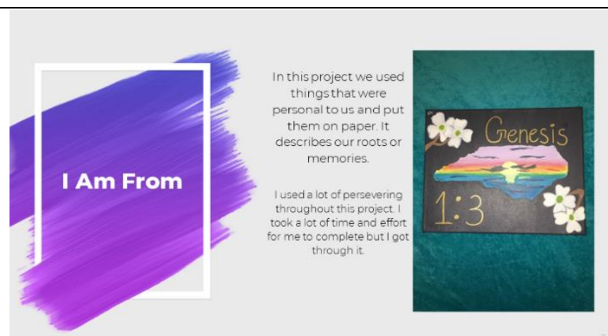












The teachers invited six students to participate in video-recorded focus groups that were conducted approximately a month apart by graduate assistants working either individually or in pairs. I met with the graduate assistants prior to the first focus group to discuss logistics of setting up the meeting room and the process of conducting a focus group with this age group of participants. Although both the graduate students and focus group participants were nervous at first, everyone became more familiar with the process, the young students shared their perspectives freely. For example, in a later focus group, students were invited to comment on the concepts of computational thinking invoked in the *Barefoot* definition by responding to focus group prompts that did not use the names of the concepts directly. Table 4 provides a synthesis of responses (the *Barefoot* term is in parentheses in the left-hand column; quotes indicate a particular student's exact words).

Table 4

Synthesis of Perspectives on the Concepts of Computational Thinking

Prompt	Synthesis of Responses
(Logic) To what extent do you make predictions about what is going to happen in art?	All the time. The artist has to work with shapes and symbols and they make predictions that a certain placement will work. But they can't know for sure how things will look until they have placed them. The same with colors. It's like experimenting. You put two colors next to each other and if it works you keep it.
(Algorithms) To what extent do you follow a set of rules for doing something in art?	We like to be free. We follow the guidelines, but there are plenty of "empty boxes [in the guidelines] that you have to fill in yourself." We do our own thing for the most part—just follow the general idea. Some things must be done in order (e.g., in creating a watercolor).
(Decomposition) To what extent do you break a problem down into simpler parts in art?	In the *Layers of Meaning* project, it was too complicated to create in a single step. For example, we had to make a grid, then place all the self-chosen symbols, sketch out the face, use a Sharpie to make the face stand out against the symbols, and then implement your color scheme. We had to break the image of our faces down into parts too.
(Patterns) To what extent do you use your ability to spot repeated designs in art and use them?	Patterns are lines or circles or squares and we just repeat them. Emojis are patterns. Sometimes we write about a topic and then choose a symbol that is in sync with what we write. For example, in the *I Am From* project, "I chose a heart."
(Abstraction) To what extent do you leave out details and focus on the "big picture" in art?	Don't focus on the details. "I was looking for a way to show integrity and chose this [holds out both hands one just above the other with palms facing]."
(Evaluation) To what extent do you make judgements about your work in art?	We compare it to [the teacher's] example or how it looks to us. We never expect ours to look as good as [the example] or compare it to a friend's. "Mine's just a little bit ugly. I want to throw it out the window, it is so ugly." "I had to make my jaw-line look a bit better and not hanging."

In general, I liaised with the teachers to ascertain what curricular activity the students were working on and then met with the graduate assistants in the week prior to the focus group sessions to decide on open-ended prompts related to that project. For example, after *Digital Mondrian* (see Table 2) students were asked

Tell me about the *Digital Mondrian* project. Was it interesting?

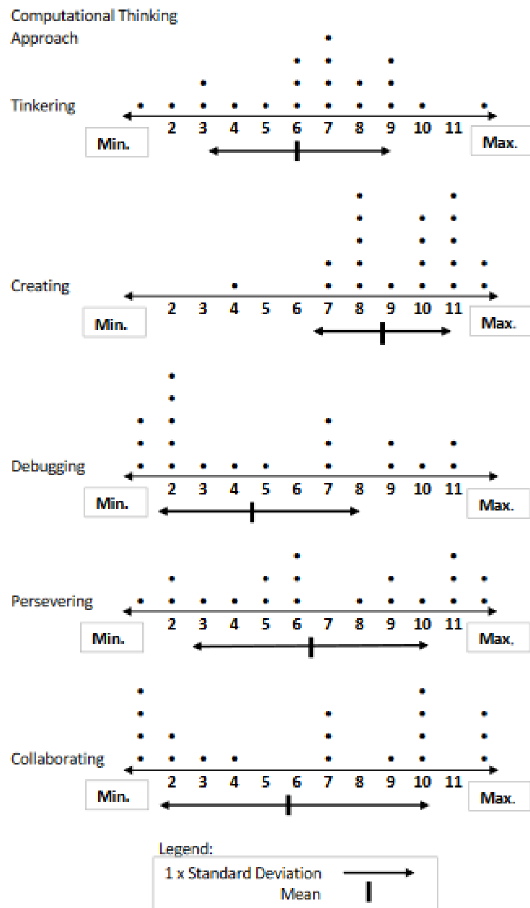
- Would you like to show it to me so you can tell me about it more effectively?
- What was the biggest challenge?
- What would you do differently if you had the chance to do it again?

In terms of the approaches that students adopted, we gained formal insight by inviting them to place a mark on a paper copy of continuum lines drawn underneath the names of the approaches to show the extent to which they utilized each of the approaches. Each of the continuum lines were labelled simply “not at all” at the left-hand end and “to a great extent” at the right-hand end with no intermediate dividing lines (to leave students more freedom). When we received their responses, we superimposed an evenly spaced numbered line and transformed each student’s response to a stacked “dot” on a Microsoft Excel spreadsheet, as shown in Figure 1, to produce a frequency distribution. The mean was indicted on an additional double-headed arrow underneath each frequency distribution with the length of the arrow indicating the standard deviation of the students’ responses. In this way, the teachers were provided with a completely visual sense of how the students used the approaches in each curricular activity system project.

The focus group meetings and the approaches feedback forms gave us an ongoing sense of how the students were experiencing the computational thinking elements that were embedded in the various curricular activity system projects. The formal feedback channels confirmed the teachers’ everyday observations that the students’ engagement was consonant with the design of the projects and sometimes led students to deeper insights. One example related to the Layers of Meaning: Palimpsests project (see Table 2). Students were invited to conduct their own research into what a palimpsest is before they set about constructing a layered product of their own. In a subsequent focus group, one of the students complained heartily about being expected to overlay their initial artwork with a second layer of artwork: “I had to make a mess of my own work.” They were invited to reflect on why palimpsests emerged and the political or religious factors that medieval scribes might have considered in selecting parchments (palimpsests, in general, do not contain complete sets of original writing) to be overwritten (e.g., discredited religious texts, outdated account records). This invitation transported a very intelligent student into a consideration of a social order very different from their own.

Figure 1

Student Feedback on Approaches Adopted



Reflections and Recommendations

In Leontiev's (1971) introduction to Vygotsky's *The Psychology of Art*, he pondered how to achieve the metamorphosis of feelings that distinguished works of art from pictographs. He asserted that "the nature of the process itself is hidden from the investigator, just as it is concealed from the observations of the artist" (p. vii). Sussman (NRC, 2010) depicted a skillful poet who, seeking to induce an emotion in the reader, "takes pieces that have parts of that emotional state, [and] puts them together in the right way . . . so as to make a larger structure that has that property" (pp. 15–16).

We adopted the operational definition of computational thinking developed in conjunction with the ongoing *Barefoot* project in the United Kingdom (Computing at School, 2020). Although oriented to early years students (up to 11 years-of-age), we believed that the *Barefoot* concepts and approaches provided us with a robust supportive framework for the curricular activity system (Roschelle et al., 2010) that we envisaged creating at the middle school level (Reardon & Webb, 2019). As Roschelle et al. (2010) discussed, the use of the word "curricular" conveyed that our project was intentionally designed as a learning progression, the word "activity" highlighted that the components of the curricular activity system were activities in which both the teacher and the students engaged, and the word “system” adverted to the fact that we envisaged “an aligned set of related components that coherently support the . . . curricular activities” (p. 239).

We consistently focused students’ attention on the fact that the digital technologies integrated into the curricular activity system components enhanced their ability to respond artistically and facilitated their ability to both demonstrate and develop their visual literacy. As Lodi (2020) recently pointed out, there continues to be little agreement among proponents of computational thinking regarding the definition of the term. Nevertheless, Lodi distilled some common themes and suggested that computational thinking involves technical and practical expertise but also includes a computational thinker’s possession of a range of mental attributes such as “creativity, collaboration, tolerance for ambiguity, [and] resilience” (p. 113)—all subsumed under the concept of “transversal competencies” (p. 113).

We concurred with Ioannidou et al. (2011) that middle schools are ideal contexts for increasing and broadening participation in computational thinking because students at this stage are “reaching conclusions regarding their own skills and aptitudes” (p. 3). Middle school has been acknowledged for decades as a challenging time in the development of adolescents (Eccles & Roeser, 2011; Goldstein et al., 2015; Lord et al., 1994; Simmons & Blyth, 1987). During middle school, students are experiencing major physical and psychological changes while they are also facing social challenges and dealing with issues of identity formation. The transition from elementary to middle school can be anxiety-inducing and Goldstein et al. (2015) found that higher transition stress was associated with problematic academic outcomes including lower grades, higher school anxiety, and lower school bonding.

In the long term, sub-optimal academic outcomes are also problematic in that, according to Carolan et al. (2015), middle school performance is a predictor of the student’s overall achievement for the rest of their educational career—a student whose grades begin to decline in middle school is more likely to have worse grades in the future as well as facing behavioral and social challenges. It is important to note that student achievement outcomes are impacted by more than students’ personal contexts. Carolan et al. found that classroom environment and the quality of classroom instruction played a major role in student performance outcomes. They asserted that the socioeconomic status of the family and the available resources of the school district modulate the educational context—both factors were major considerations in establishing iCS4All.

In closing, we contend that our approach to integrating computational thinking with the teaching of visual arts in iCS4All boosted students’ transversal competencies (Lodi, 2020, p. 113) and will increase the likelihood that the benefits will outlast the duration of iCS4All. In this vein, President Obama’s vision was translated into action in the synopsis that prefaced the Computer Science for All grant solicitation site on the National Science Foundation (NSF, 2020) website by referencing “research-practitioner partnerships (RPPs) that . . . provide . . . preK-8 teachers with the instructional materials and preparation they need to integrate CS [computer science] and CT [computational thinking] into their teaching” (para. 1).

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About the Author

R. Martin Reardon, PhD, is an associate professor in the Educational Leadership Department of the College of Education at East Carolina University (ECU). Reardon joined the department in 2014 and accepted an invitation in 2017 to also join colleagues as an affiliate faculty member of the ECU Rural Education Institute (REI). Within the department, Reardon teaches a range of courses in the Educational Doctorate program focused on the design and implementation of problem-of-practice dissertations utilizing quantitative, qualitative, and mixed methods approaches. He earned his PhD in Educational Policy, Planning, and Leadership from The College of William and Mary in Virginia in 2000. After graduation, Reardon was on the faculty at Marian University (Wisconsin) for 4 years and was the inaugural Chair of the Educational Studies Department there before joining Virginia Commonwealth University and then ECU. Prior to his career in higher education, Reardon held a wide range of teaching and administrative positions in two states over the course of his 27-year career at the high school level in Australia. Reardon's recent publications have focused on school/university/ community collaboration as a context for change and he has edited/co-edited ten book volumes addressing this topic. He was the executive Co-PI on a recently completed $1 million National Science Foundation grant to integrate computational thinking with the teaching of music and visual arts in three rural eastern North Carolina school districts. With colleagues in REI, he has engaged in the conduct of mixed methods research into the social emotional welfare of elementary students and is currently collaborating in the conduct of a research project inquiring into learning recovery in the COVID-19 context.

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Rural Secondary STEM Teachers' Understanding of the Engineering Design Process: Impacts of Participation in a Research Experiences for Teachers Program

Teresa Shume, *North Dakota State University*
Bradley Bowen, *Virginia Tech University*
Jewel Altimus, *Virginia Tech University*
Alan Kallmeyer, *North Dakota State University*

Though STEM teacher professional development is known to be beneficial, it is not available equally to educators in all geographic regions. Rural educators face unique challenges not often experienced by their urban and suburban counterparts. This study investigates the impacts of a Research Experiences for Teachers (RET) program on rural math, science, and technology education teachers' perspectives on how these experiences changed their understanding of the engineering design process (EDP). From 2016 to 2019, eleven rural secondary STEM teachers engaged in a six-week professional development experience focused on research and implementing the EDP. These teachers were rural "solitary" STEM teachers, which meant they were the only teacher of their subject in their school building. This qualitative study used a thematic analysis approach to code and analyze individual and focus group interview transcripts. The results were analyzed to determine how the RET experiences impacted the teachers' perception of how the EDP is used in problem-solving activities and how it could be integrated into their classroom practices. Results from this study show that the teachers developed a more authentic conceptual understanding of the EDP, which led to increased insightfulness on how to engage students in authentic engineering design activities that strengthen future workforce skills. This study demonstrated that an authentic engineering-based RET program can increase rural teachers' commitment and readiness to incorporate the EDP into regular classroom practices. Further, this program resulted in teachers gaining a much more nuanced understanding of how the EDP's non-linear steps and iterative nature contribute to creating authentic problem-solving challenges for students. In particular, the teachers realized the necessity of creating less prescribed challenges that require students to draw upon the constellation of skills necessary to design optimal solutions, resulting in higher-caliber opportunities to develop future workforce skills. These findings emphasize the critical need to design professional development experiences that target the unique needs of rural STEM teachers. Additional research is needed to tease out the extent to which teachers' increased commitment to using the EPD and a more nuanced understanding of the EDP translate into sustained changes to classroom practice.

***Keywords*: rural teachers, STEM education, engineering design process, research experiences for teachers, professional development, qualitative methods**

Science, Technology, Engineering, and Mathematics (STEM) education is a significant dimension of national conversations on education. The skills necessary for students to be successful in the future workforce include collaboration, communication, critical thinking, and creativity (i.e., the 4 C's) as well as other 21st century skills such as problem-solving and design thinking, referred to in this document as "workforce skills" (National Science and Technology Council, 2018; P21, 2019). Exposing teachers and students to the engineering design process (EDP) has become a national imperative to prepare students for the future workforce as effective implementation of the EDP incorporates many desired future workforce skills. However, the ability to effectively integrate the EDP in school classrooms usually requires targeted professional development explicitly focused on the understanding and implementation of the EDP (Parker et al., 2020). Providing opportunities for teachers to improve their teaching practice is essential for improving the student learning experience (Anderson & Tully, 2020; Darling-Hammond & Baratz-Snowden, 2005; Guskey, 2002; Landis et al., 2011; Wei et al., 2009). Specialized professional development experiences are vital for rural educators because they face challenges that differ from those encountered by teachers in urban or suburban school districts. Rural educators often lack access to professional development about the EDP (Parker et al., 2020; Showalter et al., 2019) and require unique solutions to their professional development needs.

Professional Development in STEM Education

Integrating engineering or scientific research into teacher professional development has shown to increase teachers' awareness of the need to incorporate authentic learning activities into their classroom practices regularly (Barrett et al., 2015; Barrett & Usselman, 2005, 2006; Basalari et al., 2017; Bowen et al., 2018, 2019, 2021; Farrell, 1992; Kantrov, 2014; Silverstein et al., 2002, 2009). Teachers have reported a shift in their pedagogical approach to incorporate the use of more workforce skills in the classroom as a result of participating in targeted professional development (Bowen & Shume, 2018, 2020; Darling-Hammond & Baratz-Snowden, 2005; Stewart, 2014; Webb, 2015). Through such pedagogical approaches, teachers provide opportunities for their students to engage in authentic 21st century learning (Landis et al., 2011). Comprehensive programs designed to target these pedagogical shifts, such as the National Science Foundation's (NSF) Research ss for Teachers (RET) Program, can provide highly effective professional development for teachers (Bowen et al., 2018, 2019, 2021; DeJong et al., 2016).

Barriers for Rural Educators

Though STEM teacher professional development is known to be beneficial, it is not available equally to educators in all geographic regions. Rural educators face unique challenges not often experienced by their urban and suburban counterparts. Geographically, the distance between cities, towns, or educational communities creates barriers to finding and attending high-quality professional development activities (Showalter et al., 2019). Rural educators often teach multiple courses and grade levels, requiring substantial time commitments to prepare lessons for multiple course subjects and student knowledge levels (Barley & Brigham, 2008; Goodpaster et al., 2012). Given the additional planning load necessary to design course materials for such a wide variety of curricula, these teachers face significant barriers to making transformational changes in their teaching practices. Rural school structures may also be more resistant to change, increasing the difficulty for STEM educators to implement innovative teaching methods

(Goodpaster et al., 2012). Moreover, rural schools face funding barriers for providing quality professional development and properly equipped educational facilities (Player, 2015; Williams, 2010). Compared to urban and suburban educators, rural educators also report less access to quality professional development, professional learning communities, and other collaborative supports such as common planning times and opportunities to observe their peers (Glover, 2016; Lavalley, 2018; Wei et al., 2009).

Rural Educators in STEM Education

Over and above the barriers commonly experienced by rural educators, rural STEM educators face additional layers of challenges. Rural areas in the United States have higher teaching position vacancy rates in STEM content areas than non-rural areas (Dee & Goldhaber, 2017; Player, 2015). Due to the large number of vacancies, it can be difficult for rural STEM educators to receive support and proper mentorship from their peers and supervisors (Lavalley, 2018), one of the primary negative factors of rural STEM educator retention (Goodpaster et al., 2012). These teachers also reported a lack of access to research and specialty community-based or university-based resources and programs due to the lack of offerings and the geographical distance necessary to attend (Player, 2015).

The EDP for Rural STEM Educators in RET Programs

There exists a significant need for more engineering-related professional development for rural educators (Ficklin et al., 2020). RET programs are an example of how teachers can engage in engineering-focused professional development by participating in authentic research projects. The outcomes of one RET program that engaged high school science teachers in rural Michigan showed the teachers developed a positive change in attitude toward using engineering in the classroom and an increased amount of integration of engineering concepts into their classroom activities (Yelamarthi et al., 2013). The teachers also reported an increased understanding of the concept of the EDP and the use of collaborative instructional practices (Yelamarthi et al., 2013). In other engineering-focused RET programs, teachers reported learning the benefits of using the EDP to increase student engagement (DeJong et al., 2016), developing higher levels of confidence in integrating the EDP into their science instruction (Pinnell et al., 2013), and enhancing their instruction by incorporating authentic engineering applications (Reynolds et al., 2013). Effective RET programs can improve participants' confidence and readiness to integrate engineering concepts into their classroom practices through the use of the EDP.

Professional development centered on the EDP needs to foster depth of understanding about key aspects of the EDP. When designing solutions to a given problem, engineers implement the EDP. This process consists of several constructive steps, such as asking questions, conducting research, and creating prototypes. It is a non-linear iterative problem-solving process that is inherently open-ended, with multiple solutions being plausible. Integrating the EDP into classroom activities allows students to utilize and develop future workforce skills. However, the EDP can be messy, and integrating it effectively into classroom activities requires a skilled pedagogical approach. For example, when implementing activities that utilize the EDP in the classroom, the teacher should promote a student-centered classroom management approach to guide student thinking and promote student learning by asking probing questions (Garrett, 2008; Krahenbuhl, 2016). In this role, educators are auxiliary to student learning, contrary to many traditional teaching methods. Many teachers are hesitant to undertake this approach because this teaching style may be unfamiliar, and they have not had the proper training (Cejka & Rogers, 2005; Guzey et al., 2014; Hammock & Ivey, 2017; Lottero-Perdue & Parry, 2017).

The RET program in this study was uniquely designed to engage rural teachers in authentic research by utilizing the EDP. The focus was the process of engineering design and not on gaining additional or specific content knowledge; nonetheless, content knowledge was implicitly learned through the RET activities. A concrete understanding of the EDP is at the forefront of engaging students in authentic design experiences that foster future workforce skills.

Research Question

The current research project reports data collected from an NSF-funded RET program at a university in the upper Midwest. The RET program provided "solitary" rural STEM teachers with an immersive research experience focused on the knowledge and skills required to integrate the EDP into their classroom practices within an agricultural framework. The research question guiding this study was: How do rural secondary mathematics, science, and technology education teachers describe the impacts of an engineering-based RET program on their understanding and approach to integrating the EDP into classroom practices?

Program Description

The three-year RET program in this research study was conducted from 2016 to 2018 at a university in the upper Midwest of the United States. The researchers also used a one-year no-cost extension in 2019 to offer additional professional development activities both virtually and on-campus. The participants included five in-service and five pre-service teachers each year, with one in-service and one pre-service teacher working in a pair throughout the program. The six-week program engaged the teachers in research incorporating the EDP through an agricultural context since agriculture is a significant influence in the region. The faculty-led research projects incorporated the development of electrical hardware, software design, and bio-based materials to investigate sustainable materials and precision agriculture. A few project examples include Electrical Properties of Bio-Composite Materials, Development of Thermoplastic Bio-Based Composites for 3D Printing, Measurement of Plant Growth Effect on Wireless Sensor Signals, Statistical Analysis of Moisture Sensor Performance, and Development of Bio-Based Resins from Vegetable Oils.

Program activities incorporated some of the best practices that research literature suggests on effective professional development. Some of these include consistent interaction between the teacher participants and the project team (Guskey, 2002; Guskey & Huberman, 1995; Parker et al., 2015; Sunyoung et al., 2015), multiple opportunities to model the desired K-12 learning activities (Bang, 2010; Guzey et al., 2014), and shared experiences with colleagues (Barrett & Usselman, 2005, 2006; Fullan & Hargreaves, 1992; Guskey & Huberman, 1995; Loughran, 2002). During the academic year, follow-up collaborations were provided to support each participant as they translated their research experience into classroom practices. Other support systems were provided, such as equipment and materials to incorporate newly developed classroom activities and the establishment of a virtual rural STEM educator professional learning community. At the conclusion of each summer experience, the teachers created a poster for a campus-wide research symposium and presented their research to several different audiences.

After the teachers implemented one of their new lessons, they were required to reflect and refine the lesson design as part of the submission and approval process for the teachengineering.org website managed by the University of Colorado at Boulder.

Methods

Given the interpretive nature of the research questions driving this research, thematic analysis was selected as this study's methodological approach. Thematic analysis is a process for finding patterns of meaning in qualitative data through cycles of reading and rereading to identify key themes (Braun & Clark, 2006; Flick, 2014). Using NVivo software, researchers coded the data and collated codes into themes. As described by Braun and Clark, a theme "captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set" (2006, p. 82). The data were analyzed to identify patterns of meaning in the teachers' viewpoints on how the engineering-based RET experience influenced their classroom practices.

Study Participants

This research study included five in-service and five pre-service teachers each year, with one in-service and one pre-service teacher working in a pair throughout the program. The in-service teachers were classified as "solitary" rural secondary STEM teachers, meaning they were the only mathematics, science, or technology education teacher in their school building for grades 6-8, 9-12, or 7-12. To recruit in-service teachers for the program, the researchers contacted the local Regional Education Associations in the upper Midwest region of the United States to identify teachers that met this qualification. The researchers contacted these teachers by email to determine their interest in participating in the RET program; consent to participate in the research study was obtained separately. Although pre-service teachers were part of the RET program, for this research project, the researchers focused only on the research outcomes of the in-service teachers.

Seven teachers participated for one year, and four participated for two years; therefore, a total of eleven in-service teachers participated in the RET program and research study. Three participants were male, and eight participants were female. All the in-service teachers taught either mathematics, science, or technology education (referred to in this study as "STEM" courses). In some cases, they taught more than one STEM subject with some additional non-STEM teaching responsibilities, such as English Language Arts or social studies. Table 1 describes the RET in-service teachers who participated in this study. For the remainder of the article, study participants will be referred to as "teachers," and their content area will be referred to as "STEM."

Table 1

RET participant descriptions

Participant Pseudonyms	Years of Participation	Gender	Grades Taught	Subjects Taught
Amber	2016, 2018	Female	8-12	Biology
David	2016, 2017	Male	7-12	Biology, Chemistry
Austin	2016, 2017	Male	7-12	Math, Science
Kayla	2016	Female	9-12	Biology, Chemistry
Leigh*	2016	Female	7-12 4-8	Biology, Chemistry, Science ELA**, Science, Social Studies
Jake	2017	Male	8-12	Science
Anna	2017	Female	7-12	Science
Ashley	2017, 2018	Female	9-12	Math, Science
Erin	2018	Female	7-12	Science
Jessica	2018	Female	6-8	Science, STEM, Social Studies
Emily	2018	Female	K-12	Technology Education

* Leigh taught in two different schools and multiple subjects during the research project
** ELA=English Language Arts

When a STEM subject is listed in the table, it indicates the teacher was the only one who taught that subject in the school building for the grade levels listed. If a teacher taught more than one course within a specific subject area, it was common for them to refer to their courses using a general term (i.e., using the term "science" to describe multiple science courses) instead of referring to each course separately.

Data Collection

Individual in-person interviews were the primary method of data collection for this study. The semi-structured interview protocol consisted of a set of core questions asked at every interview, along with additional probing questions posed by the interviewer to explore topics of interest raised by the participants. Each summer, every teacher was interviewed individually during their time on campus participating in the RET program. The teachers who returned for a second summer in 2017 participated in group interviews. Additionally, second interviews were conducted in the fall with the teachers who participated in 2018; most of these interviews took place in person, but a small number were conducted over the phone due to geographic distance. The interviews, approximately 30–45 minutes in length, were audio-recorded and transcribed verbatim for analysis.

Data Analysis

To search for patterns of meaning in the interview transcripts, the researchers followed Braun and Clark's 6-phase guide to perform thematic analysis. In particular, the researchers undertook an iterative process that involved the following phases described by Braun and Clark

(2006): "1) familiarizing yourself with your data, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, 6) producing the report" (p. 86). Importantly, this methodological approach does not consist of a linear set of steps completed sequentially, but rather a "more recursive process, where movement is back and forth as needed, throughout the phases" (Braun & Clark, 2006, p. 86). The themes produced by this thematic analysis are consistent with Patton's (2015) criteria of internal homogeneity and external heterogeneity. In other words, each theme is coherent within itself but distinct from the other themes.

Findings

The thematic analysis produced four themes that captured repeated patterns of meaning expressed by the teachers during their interviews. The four themes are an increased focus on the EDP, the teachers' development of a more authentic and sophisticated conception of EDP, teachers' recognition of the importance of student metacognition during the EDP, and teachers relating and empathizing with students' experiences implementing the EDP.

Theme 1 - Increased Focus on EDP

Teachers were immersed in experiencing and implementing the EDP while engaged in authentic engineering research projects daily throughout their summer experience. For some teachers, the centrality of the EDP in their daily work during the summer experience served to reinforce the importance of having students apply the EDP in their classrooms. For others, their RET experience initiated a major change in their view on the role of the EDP in their teaching. For example, Jake said,

> I have seen how this engineering design process works . . . It's a blueprint. It's a road map, whatever you want to call it, to succeed at designing. I've never shared that with students before. I've never cared about it before. This has been kind of eye-opening.

Similarly, Amber explained,

> Before I came, it [knowledge of EDP] was very, very limited. It wasn't something that we really focused on when I was in my undergrad [degree program]. It was definitely not something we focused on when I was in school, like high school or anything. Before the [RET] program at all, I had very limited knowledge . . . That's really my main focus coming out of this summer. I really want to incorporate more engineering design into all of my classes.

One of the most prevalent themes was that teachers came to recognize and deepen their understanding of the value of making room for classroom learning experiences that engage their K-12 students in the EDP.

Theme 2 - More Authentic Conceptions of EDP

Over the course of the program, most teachers developed a more nuanced and sophisticated conception of what the EDP is and how it works. Through participation in the RET program, many teachers came to more fully understand that the EPD is not a linear set of steps but rather an iterative process that involves a kind of messiness that is not neat and straightforward. Leigh explained,

> Kids really like black and white and I think it's why teachers go there so often. . . . Realistically, I think that's the easier way to go and so a lot of us get stuck doing that because the kids like it because there's a clear yes, no, there's a clear right, wrong . . . but that's not realistic. Real life isn't all black and white, it's not right and wrong, you've got errors and you've got troubleshooting and you've got all of these steps in between.

Like other teachers in the program, Kayla expressed an increased commitment to providing her students with classroom learning experiences that aligned more authentically with the fundamental nature of the EDP. She said,

> Looking back at how I've been teaching where it's like I kind of lost that in-between
>
> problem-solving–research component. I've wanted them to have their results without having to put all the effort in, I guess? And I'm realizing now that that's not the path that I want to go down, that staying more true to the ingenuity and the design process and research process . . . I really have, like I said, really gotten that sort of renewed, I don't know what to call it, the renewed idea or the renewed, lack of a better word, passion for the research that goes into it and the real experience of it.

Teachers came away from their RET experience with a deeper understanding of the iterative nature of the EDP, particularly with regards to the role of multiple design revisions based on repeated testing. This increased awareness translated into an increased commitment to attending to the authenticity of classroom EDP experiences for students.

Theme 3 - Importance of Student Metacognition about EDP

Many teachers reported that prior to participating in the RET program, they would have their students apply the EDP without engaging in authentic reflection about it. Some teachers indicated that when they had their students use the EDP in class, the learning activities involved moving through the steps of the EDP without calling attention to explicitly identifying the steps. Others indicated EDP steps were named, but they missed opportunities to have students reflect on their use of the EDP. A representative quote from Jessica stated,

> I think really looking at reflecting on what went right, what didn't go right. I want to really bring in that reflection piece and making sure that students are writing down their steps. What step of your engineering design process are you in? What is happening? Make sure you're writing data. Because I know I haven't really expected them to do that before, and I think that's a huge piece to this [RET] project, was the reflection on data, and more purpose behind it versus just build it and move on.

When Erin described the changes to her classroom practices after participating in her summer RET experience, she explained,

> I probably focused on one, the authenticity, and then two, the redesign a lot more this time around because historically we just do a project and then the project's over. So now we spend a little bit of time, "Okay, take those questions that your classmates asked you and how is that going to change where you go moving forward?"

After participating in the program, teachers reported increased awareness of the importance of slowing down and making time for students to recognize the steps of the EDP as they progressed through class projects. They also acknowledged that students need time to record their reflections and to ensure they are truly using their collected data to make design decisions. Teachers related this change toward fostering small and large group reflection in the classroom with the daily conversations and weekly research meetings that took place during their summer experience.

Theme 4 – Relating to Student Experiences with EDP

Another theme that emerged in this study came from what teachers gained through direct participation as a team member working through problem-solving while engaged in the EDP. Teachers discussed insights that arose from reflection on their summer experiences that allowed them to better understand and empathize with what students experience when engaged in design-based learning activities in the classroom. For example, Emily explained,

> I think for us to go through and experience the frustrations of certain things and just to know if we bring this back to the classroom, this is what students are going to be feeling, and working together with a team, and trying to throw in your ideas, and then come up with an idea that all of you are excited about doing.

A quote from Anna describes her increased awareness of the need for students to have sufficient time and opportunity to grapple with the EDP, a realization experienced by several teachers.

> Like I said, it's been a long time since I've been in a lab and done some actual hands-on research. And I think, well I know, I forgot that sometimes the problem-solving part of things takes longer and that piece of things actually sometimes takes more of the time than the actual product, once you get the process down. . . . And so I'm excited to take that kind of process back to the kids and being able to kind of present them with a problem of, "This is what we want, how do we get there?" And seeing the different paths that they take because depending on how they decide to go about it, they'll all run into different problems.

The RET summer experience brought several opportunities for teachers to step into the shoes of their students. Teachers reported that through their RET experience, they were reminded that feelings of uncertainty and frustration are a typical part of engaging in the EDP and that working together as a team requires time to explore potential solutions and work out the differences between team members.

Discussion

This research project investigated how rural mathematics, science, and technology education teachers described the impacts of an engineering-based RET program on their understanding and approach to integrating the EDP into classroom practices. Looking across the four themes produced by this study, two notable impacts are worthy of further consideration.

First, the teachers gained a stronger appreciation of the importance of using the EDP to engage students in authentic problem-solving as part of their regular classroom practices. They expressed an increased commitment to granting students more responsibility for navigating their way through the process and providing additional time to struggle with the iterative nature of designing. This outcome supports existing research reporting that teachers are significantly more motivated to integrate the EDP into their classroom practices after participating in an authentic engineering-focused RET program (Bowen et al., 2018, 2019, 2021; DeJong et al., 2016; Yelamarthi et al., 2013). Teachers in this study also expressed ownership and buy-in for implementing the EDP due to increased familiarity with the nature of the EDP and readiness to translate it from an engineering research setting into a classroom setting. Similar to the findings of Du et al. (2019) and Hart (2018), this shift in thinking demonstrated they felt more confident to use the EDP as part of their teaching, compared to other teachers who may have been hesitant due to the lack of training and expertise with implementing the EDP (Cejka & Rogers, 2005; Guzey et al., 2014; Hammock & Ivey, 2017; Lottero-Perdue & Parry, 2017). This outcome is especially important for rural teachers who lack access to high-quality engineering-based professional development compared to urban and suburban teachers (Lavalley, 2018; Wei et al., 2009).

Second, the teachers gained a more sophisticated perception of what is genuinely involved in conducting an engineering research project and the extent to which the steps of the EDP are nonlinear and deeply intertwined. Participation in an immersive engineering research program provided these teachers the authentic experience needed to gain perceptive insights about nuances involved in conducting a formal engineering design-based project. Through this understanding, these teachers realized that their previous teaching lacked authenticity with regards to the EDP's "messiness." Teachers reported that participation in this RET experience created an awareness of the necessity to develop less prescribed instructional scenarios and allow students more time for the iterative aspect of design projects. In this way, students will have more opportunities to develop the knowledge and skills needed to persevere through the problem and produce more optimal solutions, building students' foundations for future workforce skills.

Conclusion

Rural educators, particularly in the STEM fields, encounter unique barriers when seeking to incorporate more engineering-related activities into their classroom practices (Barley & Brigham, 2008; Goodpaster et al., 2012; Player, 2015; Showalter et al., 2019; Williams, 2010). These teachers need increased access to high-quality professional development activities in order to become adequately prepared for engaging their students in learning activities focused on the EDP, a vital dimension of promoting future workforce skills. This study demonstrated that an authentic engineering-based RET program can increase rural teachers' commitment and readiness to incorporate the EDP into regular classroom practices. Further, this program resulted in teachers gaining a much more nuanced understanding of how the EDP's nonlinear steps and iterative nature contribute to creating authentic problem-solving challenges for students. In particular, the teachers realized the necessity of creating less prescribed challenges that require students to draw upon the constellation of skills necessary to design optimal solutions, resulting in higher caliber opportunities to develop future workforce skills. Overall, through participation in this RET program, the teachers gained a broader appreciation of the EDP's impacts on student learning and engagement. These findings emphasize the critical need to design professional development experiences that target the unique needs of rural STEM teachers. Additional research is needed to tease out the extent to which teachers' increased commitment to using the EPD and a more nuanced understanding of the EDP translate into sustained changes to classroom practice. Professional development that increases rural STEM teachers' readiness and commitment to implementing authentic EDP experiences in their classrooms is an essential pathway to developing rural students' future workforce skills.

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About the Authors

Dr. Teresa Shume, is an associate professor in the School of Education at North Dakota State University. She holds a PhD in Teaching and Learning from the University of North Dakota, an MEd from the University of Utah, and undergraduate degrees in biology and education from the Collège Universitaire de St.-Boniface in Canada. She has worked as a high school science teacher, college biology instructor, science teacher educator, and science education consultant. Her research and teaching focus on science teacher preparation and making science education accessible for all.

Dr. Bradley Bowen, is an assistant professor at Virginia Tech in the School of Education's Integrative STEM Education program. He has a BS in Civil Engineering from Virginia Tech and a Master's of Civil Engineering and an Ed. in Technology Education, both from North Carolina State University. Using his work experience in engineering and education, he specializes in designing integrative STEM education activities for K-12 students and professional development programs for K-12 educators.

Jewel Altimus, is a doctoral student in the Integrative STEM Education program at Virginia Tech. She received her BS degree in Interdisciplinary Studies with a concentration in Elementary Education from Radford University and her MAEd in Curriculum and Instruction from Virginia Tech.

Dr. Alan Kallmeyer, is a professor and chair of the Mechanical Engineering Department at North Dakota State University (NDSU). His technical research background focuses on the fatigue and fracture behavior of engineering materials, a subject on which he has published extensively. He has also been active in K-12 STEM outreach efforts in the College of Engineering at NDSU, establishing and expanding several programs designed to excite students about STEM careers and improve the preparedness of K-12 students and teachers to succeed in STEM disciplines.

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Rural Educational Leader Perceptions of Online Learning for Students With and Without Disabilities Before and During the COVID-19 Pandemic

Todd H. Sundeen and **Michelle Kalos,** *University of Northern Colorado*

The COVID-19 pandemic forced the temporary closing of many brick and mortar school buildings in fall 2020 while substantially changing the delivery of instruction for students with and without disabilities in rural schools. This article describes the qualitative results of an online study completed between August 2020 and October 2020 that investigated rural educational leaders' perceptions of the use of online instructional technologies before and during the COVID-19 pandemic. Rural educational leaders also shared how special education services were delivered and how parents felt about their children's learning. The early school year in fall 2020 was a critical period for rural educational leaders as they were managing persistent and evolving issues related to providing quality educational opportunities to all students. This article provides a unique portrait of that crucial moment for educators, students, and parents.

***Keywords*: rural, disabilities, technology, broadband, internet, connectivity, equity**

The Internet has substantially changed the way teachers teach and the way students approach learning. Instructional technology is no longer a luxury. Rather, the ability to access online resources for 21st century teaching and learning has become a necessity (Kormos, 2018). Moreover, the COVID-19 pandemic forced the temporary closing of many brick and mortar school buildings in 2020 while leaving families to find the means to continue student learning from home. Additionally, educators had to quickly shift to online modalities for teaching. The pandemic necessitated greater use of internet for teaching and learning. Yet, equity in access to broadband internet, student devices, and teachers fully trained in online instruction has been on ongoing issue for many schools (Jackson & Garet, 2020).

This article will describe the qualitative results of an online study completed between August 2020 and October 2020 that investigated rural educational leaders' perceptions of the use of online instructional technologies before and during the COVID-19 pandemic. Rural educational leaders also shared how special education services were delivered and how parents felt about their children's learning. The early 2020 school year time frame was a crucial period for rural educational leaders as they were managing persistent and evolving issues related to providing quality educational opportunities to all students.

Approximately one in five Americans (60 million people) live in the rural areas that make up about 97% of the nation's land area (Ratcliffe et al., 2016). However, the geographic, socioeconomic, and demographic landscape of rural settings vary greatly across America. Rural communities can be distant and remote, or they can be located a relatively short distance from a suburban setting. The racial and ethnic diversity of rural communities can resemble America from

60 years ago, or they can foreshadow the demographic changes that are remaking increasingly diverse communities across the country. About one in five students, about 9.3 million, attend rural schools. In fact, most rural students attend school in states where they account for less than 25% of total school enrollment (Showalter et al., 2019). Additionally, school sizes in rural communities are often quite small. In fact, Showalter et al. (2019) found that the median school enrollment in rural districts is only about 494 students. While rural schools face differing strengths and confront unique challenges, one of the largest challenges that rural schools face has been economic inequality (Tieken & Montgomery, 2021).

Digital Divide

The digital divide has been a part of the discussion of digital inequities since the late 1990s and early 2000s. The original definition was encapsulated by simply describing whether access to the internet was available or not (e.g., Dewan & Riggins, 2005; Novak et al., 2000). Over the following two decades the digital divide definition has evolved to describe three levels that include (a) Level 1: access to information and communication technology (ICT), (b) Level 2: variability in digital skills and digital usage, (c) Level 3: realizing beneficial outcomes as a result of using the internet including (e.g., Shakina et al., 2021; Wei et al., 2011). Each higher level encompasses the prior. In other words, Level 3 includes ICT access, skills and usage, and outcomes.

Among the factors that influence the digital divide are geographic setting (e.g., rural, urban, suburban), technology infrastructure cost and deployment, and socioeconomic factors (Reddick et al., 2020). For example, lower population density in rural settings makes installing broadband internet infrastructure less profitable for internet service providers (Riddlesden & Singleton, 2014). The digital divide is also influenced by broadband speed, a factor that affects the user's ability to effectively access the internet. Broadband speed is also affected by the number of devices accessing the internet simultaneously, as in the case of families with several school age children. Riddlesden and Singleton (2014) and Obermier (2018) reported that rural broadband speeds were slower and broadband services were costlier than in urban or suburban areas. The cost of broadband service can also be an issue in rural settings. A cost model developed by Rendon Schneir and Xiong (2016) indicated that the deployment costs for broadband infrastructure in rural areas are 80% higher than deployment in most urban areas. As a result, the potential for lower broadband service levels coupled with higher access costs continue to be issues in equitable access to broadband internet service.

Socioeconomic disparities in rural areas have also exacerbated the digital divide in terms of broadband availability or simply the availability of computing devices to connect to the internet (Jameson et al., 2020; Riddlesden & Singleton, 2014). In fact, only about 72% of rural Americans have broadband internet available at home (Vogels, 2021). Moreover, rural homes are less likely to have multiple internet-capable devices than urban or suburban families (Vogels, 2021). During the pandemic, families with multiple school age children and fewer devices may have contributed to some of the connectivity issues reported by participants in the current study.

Digital Divide in Schools

Recently, school district leaders have stated that their greatest concern during pandemic remote instruction has been equitable access to instruction (Jackson & Garet, 2020). These educational leaders also emphasized that equity in remote digital instruction has been an ongoing issue for years. They emphasized that financial resources continue to dictate the degree of digital divide that schools in rural areas encounter (Jackson & Garet, 2020). High poverty rates persist, especially in the most isolated rural areas (United States Department of Agriculture, 2019), which affects the tax base upon which most school funding is derived. As a consequence, available funding negatively affected access to technology in rural schools (Kormos, 2018) as inequities became more apparent during the pandemic.

Yet, rural schools have embraced online instructional technologies for teaching and learning (Kormos, 2021). Using online instructional technologies has provided remote schools an invaluable tool for overcoming issues related to geographic isolation (Gallegos et al., 2022). Additionally, broadband internet access has delivered opportunities for the development of 21st century skills related to communication, collaboration, critical thinking, and creativity (Kormos, 2018). The importance of reliable internet connections has been underscored by the COVID-19 pandemic while highlighting challenges faced by rural families and their ability to access broadband connections. Even though a rural school may have internet access, up to 26% of rural households may not have any internet access or limited access (FCC, 2019). Family poverty or lack of broadband infrastructure for delivering internet connections each contribute to the lack of connectivity in rural areas (Leichty, 2021).

Theoretical Framework

Inequities related to the digital divide provided the basis for identifying the theoretical framework used to guide our inquiry. While the extant literature includes varying interpretations of the term equity (e.g., Adams, 1963; Bolino & Turnley, 2008; Pick & Sarkar, 2016), the Resources and Appropriation Theory presented by Van Dijk (2017) provides the most appropriate undergirding for the current study. Van Dijk proposed five basic tenets:

1. Categorical inequalities in society produce an unequal distribution of resources.
2. An unequal distribution of resources causes unequal access to digital technologies.
3. Unequal access to digital technologies also depends on the characteristics of these technologies.
4. Unequal access to digital technologies brings about unequal participation in society.
5. Unequal participation in society reinforces categorical inequalities and unequal distributions of resources

Van Dijk's Resources and Appropriation Theory provided a foundation for examining participant qualitative responses through a lens focused on current internet technologies. The digital divide is a very real phenomenon that has persisted for over two decades (Dewan & Riggins, 2005; Novak et al., 2000) and has impacted schools in rural areas during the pandemic (Kormos, 2018). Van Dijk's theoretical lens also provided opportunities for a greater understanding of participant responses when they described some of the inequalities experienced by students as they worked to continue their learning during a period of rapidly changing factors related to the COVID-19 pandemic.

Online Instructional Technologies

As the pandemic forced the closure of schools, teachers found that they had to quickly pivot from primarily face-to-face instruction to online instruction. Teachers had to convert their lessons with little time to redesign lessons or to develop their online teaching skillset. The ability to teach using online resources depends upon on several things including the quality of the internet connection and the availability of reliable devices to access learning materials. Teachers and students without access to these basic elements cannot teach or learn effectively online.

Terminology

Some of the terms used in this article may have several common descriptions and definitions. For the purposes of this article, broadband connectivity is defined as the speed of data transfer that is available when using the internet. The Federal Communications Commission (FCC) estimates that only 52% of rural residents had 250/25 megabits per second, a reasonable broadband speed for operating four devices (i.e., phones, computers, laptops, digital televisions, etc.) in a household (FCC, 2020). Broadband connectivity can be affected by many factors including internet availability and reliability (FCC, 2020).

There are also a number of terms that are encompassed by the term teaching and learning technologies. These include web-based classroom technology, remote learning, mobile learning environments, digital learning, educational technology, e-learning, instructional technology, online learning, and e-learning technologies. For the purpose of this study, the operational definition used was developed by the Association for Educational Communications and Technology (AECT), which defined educational technology as "the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Januszewski & Molenda, 2013, p. 1). The use of teaching and learning technologies provides opportunities for teachers to create a more student-centered learning environment with less emphasis on lectures and other teacher-centered approaches (Kormos & Julio, 2020).

Learning Management Systems

Essential online learning technologies include learning management systems (LMS). LMS are internet-based systems that facilitate teaching and learning through a format that provides access to and interaction with content and assessments (Şahin & Yurdugül, 2020). Generally, LMS are used by schools as a platform for delivering instruction. Yet, prior to the pandemic, LMS may have been underutilized. In a recent study, Kormos and Wisdom (2021) found that teachers in rural schools rarely used learning management systems (e.g., Canvas, Blackboard, Google Classroom) primarily due to lack of funding to purchase district-wide access rights.

Yet, even if rural school districts can afford LMS, reliable broadband connections, and computers, teachers must be trained in their use for effective online teaching. The COVID-19 pandemic highlighted the need for all teachers, including those in rural settings, to have professional development opportunities that support the most effective use of online instructional technologies (Caglayan et al., 2021). Teaching all students, including those with disabilities, through an LMS requires professional development opportunities to ensure equity in student instruction (Tremmel et al., 2020).

Method

The current study examined the perceptions of school educational leaders in rural areas in six central U.S. states regarding technology-related issues related to teaching students before and during the pandemic. The study was initiated as a result of the COVID-19 pandemic and the resulting need for rural schools to depend more fully on their existing instructional technology.

For this study, rural educational leaders were defined as special education directors, district administrators (not special education directors), and principals. Research questions included (a) What do rural educational leaders perceive are the differences in access to internet teaching and learning technology for delivering instruction in rural districts *prior to* and *during* the COVID-19 pandemic? (b) How do rural educational leaders perceive how special education services are provided and monitored *during* the COVID-19 pandemic? and (c) How do rural educational leaders describe the feedback received from parents regarding online learning *during* the COVID-19 pandemic? Two researchers, a doctoral student and a university faculty member, conducted the survey and analyzed the data.

Participants

Participants were recruited using an email list developed by the researchers. To develop the list, state departments of education were contacted for access to their educator email lists. Six states, including Colorado, Nebraska, North Dakota, Missouri, South Dakota, and Wyoming, agreed to provide email lists for districts in rural settings. Participants included principals (n=63), district-level administrators (n=63), and district-level special education directors (n=16). See Table 1 for characteristics of study participants.

Data Collection

Research regarding instructional technologies in rural schools was limited during the beginning of the current pandemic. Since no prior COVID-specific research on this specific topic was available, the questionnaire for this study was developed based on the research questions. The survey instrument was divided into two main sections, one quantitative and one qualitative. As a result of the depth of data developed from the quantitative analysis to be presented in a separate article, this analysis examines only the participant responses from the open-ended questions. The researchers felt that the depth and richness of the qualitative responses from rural educational leaders would be best shared separately to allow for the voices of participants to be clearly represented and to permit more in-depth data reporting. Qualitative responses were derived from five open-ended questions (a) ***Prior*** to the COVID-19 pandemic, how would you describe your teaching and learning technology status overall? What could have been improved? (b) ***During*** to the COVID-19 pandemic, how would you describe your teaching and learning technology status overall? What could have been improved? (c) ***During*** the COVID-19 pandemic, how have you provided special education services? (d) How are you tracking or monitoring service minutes described in student Individual Education Programs (IEPs) ***during*** the COVID-19 pandemic? (e) What feedback have you received from parents regarding online learning ***during*** the COVID-19 pandemic?

Table 1

Participant Characteristics

Characteristic	n	%
Participant		
Role		
Principal	63	44.4
District-level Administrator (not Special Education Director)	63	44.4
Special Education Director	16	11.2
Years		
1–5 years	39	27.7
6–10 years	20	14.2
11–15 years	35	24.8
16–20 years	29	20.6
More than 20 years	18	12.8
District Size		
Less than 500 students	57	40.4
501-750 students	15	10.6
751-999 students	9	6.4
More than 1,000 students	60	42.6
Ruralicity – Miles from urban or suburban area		
1–10 miles	28	19.9
11–20 miles	12	8.5
21–30 miles	23	16.3
31–40 miles	15	10.6
41–50 miles	19	13.5
More than 50 miles	44	31.2
School Size		
Less than 50 students	9	6.6
51–200 students	57	41.9
201–350 students	23	16.9
351–500 students	26	19.1
501–650 students	6	4.4
651–800 students	1	0.7
801–950 students	4	2.9
More than 950 students	10	7.4
Free/Reduced Lunch		
1–25 %	16	11.8
26–50 %	43	31.6
51–75 %	58	42.6
76–100 %	19	14

Data Analysis

Qualitative responses to open-ended questions were analyzed using two qualitative data analysis techniques. First, a thematic analysis approach was used as proposed by Braun and Clarke (2006). The six-step approach include (1) become familiar with the data, (2) generate initial codes, (3) search for themes, (4) review themes, (5) define themes, and (6) write-up. This approach allowed for a nuanced data analysis through which data patterns were identified and themes were generated actively without influencing each other's analysis or judgement. To become familiar with the data, a spreadsheet was created through a Qualtrics download of raw data. Each researcher read through the qualitative data section of the spreadsheet to gain preliminary impressions of patterns in the data. Next, specific phrases and repeated words were counted and highlighted to help make data patterns more visible. Step 2 involved transferring data to a new spreadsheet to begin developing codes. No pre-set codes were used. Rather, codes were developed and modified as the data were reviewed for relevancy and the relationship to the research questions. After codes were developed, Step 3 began with the researchers transferring data to a new spreadsheet under the broad headings Prior and During. These headings reflected the overall emphasis of the first research question. During Step 4, researchers examined the data under the Prior and During for more specific patterns.

After completing steps one through four independently, the researchers met to complete step five where independently identified potential themes were discussed and refined. Two themes were identified by both researchers, Learning Technology and Internet. A theme relating to pedagogy and professional development was further refined through conversation and negotiation into two themes: Teaching Teachers and Teaching Students. In addition, a specific theme of Learning Platform was added to more accurately describe responses to teaching and learning technology *during* the COVID-19 pandemic. Step six, writing up findings, was completed collaboratively.

Themes were developed and refined that reflected the emphasis of each research question. Researchers agreed that there were seven potential themes under the *Prior* heading and seven different themes under the *During* heading. Five of the themes overlapped between the *Prior* and *During* headings, while two themes under each heading were unique. We asked ourselves several questions to guide our thought process. These included (a) do the themes make sense, (b) does the data support the themes, (c) am I fitting too much into each theme, (d) are there any apparent subthemes, and (e) could there be other themes in the data (Maguire & Delahunt, 2017). The result of this heuristic process was that four themes were identified for the *Prior* survey question and five themes were identified relating to the *During* survey question.

Content analysis (Morgan, 1993) was completed concurrently with the thematic analysis. The frequency and the percentage of similar qualitative comments were calculated. The use of content analysis helped to drive the selection of themes. Higher comment frequencies helped to focus the grouping of qualitative comments into potential themes. Essentially, participant statements with higher recurring frequencies were compiled into potential themes. The content analysis was conducted independently by each researcher. Individual results were compared for consistency.

Peer Debriefing

Explication through the process of peer debriefing was used to address trustworthiness of the study. An impartial peer debriefer was chosen to identify potential issues with data analysis and to minimize researcher bias. Lincoln and Guba (1985) explain, "the process of exposing oneself to a peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (p. 308). Our approach differed from that described by Lincoln and Guba (1985) in that we held the peer debriefing after data analysis was completed. The peer debriefer for this study holds her PhD in Special Education and is a colleague with deep experience in qualitative research. The peer debriefer examined the data analysis procedures and themes developed through thematic and content analysis by the researchers. The peer debriefing process allowed us to test, challenge, and validate our findings.

Four spreadsheets were included in the peer debriefing. One spreadsheet included raw qualitative data. The second and third spreadsheets were the initial content analyses completed by the researcher and doctoral student. The fourth spreadsheet consisted of the final qualitative data groupings that were used by the researchers for identifying study themes. The peer debriefer examined the data for emerging themes, relationships in the data, and potential coding considerations (Spall, 1998). She provided several suggestions related to the content analysis that was used for developing themes derived from the qualitative feedback received from study participants. Her overall conclusions confirmed that the data analysis procedures and theme interpretations were appropriate for this study.

Findings

A total of 4,649 email addresses received the questionnaire as the survey was distributed between August and October 2020. Two reminders were sent to non-respondents and a final email request was sent at the end of October 2020. Survey responses totaled 156 with for a response rate of 3.3% and completion rate of 62%. The researchers felt that the demands of the pandemic on school administrators may have prevented them from investing time into participating in survey studies, which resulted in a low survey response rate for the current study.

The data analysis in this study centered on discovering the perceptions, learning, and responses of individuals given the influence of the COVID-19 pandemic. Overall, we examined what educational leaders learned from this unprecedented experience.

As a result of the qualitative data analysis process, an overarching theme of *Equity* became the umbrella encompassing all other themes emerged. Within the scope of the current study, participants expressed an overall feeling of not being able to do enough to support all students equitably relative to teaching and learning online during the COVID-19 pandemic. This was especially apparent when faced with the internet issues present in rural school districts represented in this study. One rural educational leader captured this overarching sentiment, "A huge concern is lack of internet access for our students. I view this as a major equity issue. Many of our families do not have reliable internet access."

Respondents indicated that very few school districts had enough computers and tablets to provide 1:1 devices for teachers and students when online learning became necessary. Educators shared their concerns about technology equity, with the following statements, "We could have improved the equity of access to tech in the classrooms" and "Needed updated technology/devices, needed more devices, and needed a lot of professional development." Since districts had not been providing sufficient devices and useful software programs prior to the pandemic, the online learning created inequity in instruction and expectations of students' performance" and "Too many programs and lack of standard expectations led to inequities in instruction." Survey results indicated that the digital divide that exists in rural America has never been felt more keenly than during the COVID-19 pandemic. Other themes revealed in the data further support this umbrella theme of (in)equity.

Teaching and Learning Technology Status *Prior* to the COVID-19 Pandemic

Responses to the survey questions, ***Prior*** *to the COVID-19 pandemic, how would you describe your teaching and learning technology status overall? What could have been improved?* were coded into four different themes. The themes that emerged included *Learning Technology, Internet, Teaching Students, and Teaching Teachers*. Content analysis for frequency and percentage were calculated. Percentage is based on the number of responses for each theme compared to the total participants who provided comments on the survey (n=117). See Table 2.

Table 2

Themes from Teaching and Learning Technology Status Comments - ***Prior*** *to the COVID-19 Pandemic*

Theme	n	%	Representative Comments
Learning Technology	63	54	"Compared to many more affluent districts, we had less technology available for student use. We operated primarily with Chromebooks on carts…shared among electives…in some cases, the size of the class exceeded the number of computers on the cart."
Internet	42	36	"…internet at home is very very poor in general and ridiculously poor for most." "old laptops, several computer labs with old desktops, and our internet would go out frequently."
Teaching Students	20	17	"Very poor…old curriculum not available online."
Teaching Teachers	73	62	"Did not have consistent exposure to online learning platforms and communication platforms."

The theme *Learning Technology* encompassed participant comments related to laptop computers and tablets, how many students had devices, and descriptions of support for those devices from technology experts within the school districts. The *Internet* theme was defined as statements centered around internet access that included descriptions of bandwidth reliability issues experienced by both students and teachers. The theme described as *Teaching Students* was framed by statements describing how students were being taught and how they were accessing their learning experiences in person or remotely. The *Teaching Teachers* theme emerged from rural educational leaders' descriptions of issues related to supporting teachers in the world of online teaching and learning. Comments about competency in devices, technology, access, and online/remote pedagogy also helped form the *Teaching Teachers* theme.

Learning Technology

Study participants' accounts of issues related to learning technology access prior to the COVID-19 pandemic included descriptions that ranged from having 1:1 devices for students and teachers to a single computer lab or a cart of laptops/tablets shared among the whole school. Educational leaders shared that devices provided 1:1 occurred most often in secondary grades while K-6 grades had only occasional device access. One participant described a favorable status, "Prior to COVID-19, all high school students were assigned a computer. We had chrome [sic] books available in carts for each grade level K-8." While other participants shared statements such as, "Had just one computer for every two students," and "We had a few computer carts with old laptops, several computer labs with old desktops, and our internet would go out frequently," and "In the high school, five or so teachers are sharing a single lab/cart."

Device access was only one of the issues related to learning technologies. Some school districts used little or no technology or used it to supplement their classroom teaching. When technology was available, it was often underutilized as captured in this respondent statement, "It is available but not many teachers were using it." Another educator shared, "I could and did use it, but in my sped classes, face to face [sic] was much more effective and online was just to supplement learning." Even when technology was available, it was underutilized: "Technology availability was good. Effective use of technology for learning was fair to poor." It appears that the use of technology in the classroom was often based on each teacher's choice for whether to integrate technology into their teaching. "Tech access mostly depended upon individual teacher interest. If a teacher wasn't interested, the kids in that room were not benefiting from tech."

Ruralness also played a role in the use of teaching and learning technologies, as summarized clearly by one respondent, "We were behind, but we are a small, rural community & it wasn't emphasized as much because our world still involves face-to-face contact 'accounts' as the local stores, writing checks, etc.)."

Internet

This theme describes respondent feedback related to internet access and broadband reliability issues prior to the pandemic. Overall, participant comments indicated that, prior to the COVID-19 pandemic, communities and their schools struggled with internet access. Descriptions of school situations where there was either no connection or the connection was unstable were frequent in the qualitative data. The need for increased bandwidth was stated by a number of respondents, "We always have problems with internet speed and reliability" and "We are at the mercy of the internet company" were representative statements.

Yet, not all access to the internet was limited: "We have a phone company in town that has an internet component, so our school has strong consistent internet both wired and wireless." However, internet access was described as an issue for families. Their experiences are well summarized by one participant as, "Multiple children and adults in the family needing access to internet and computers made it difficult for all to work at the same time. Often there was a loss of bandwidth with too many devices operating." The limited availability of reliable broadband internet clearly created issues for families and contributed to the lack of equity in learning experienced in rural areas during the pandemic.

Teaching Students

The teaching and learning technology status of teaching students prior to the COVID-19 pandemic included participant descriptions of occasional blended learning, flipped classrooms, and the use of computer learning as replacement activities. One respondent stated, “Teaching with technology was across the spectrum. Some worked exclusively through Google Classroom, some used no technology at all.” Another shared, “It was minimal at best. Some of our teachers would do the flip(ped) classroom.”

Many schools had not yet made the move to using technology for daily instruction prior to the pandemic. “Most in-district classes were traditional with textbooks [sic], lecture, and hands-on activities though many classes were available to students through on-line and ITV modes of delivery.” ITV (Interactive TV) describes synchronous LMS where real-time instruction is provided to students in different viewing locations.

Teaching Teachers

Even without the influence of the pandemic forcing brick-and-mortar school closures, teaching and learning technology requires training through ongoing professional development to insure its effectiveness. Yet, survey respondents indicated that the status of training teachers for technology use in classrooms *prior* to the COVID-19 pandemic was “sporadic and inconsistent.” Participants suggested solutions of “additional staff development to improve our teachers’ knowledge of best practices of technology use” and “Specific training for online learning has only included grades 6 to 12 at the moment.” One educator summed up the issue thusly, “I would say for a rural district, we were slightly above average. The main challenge is professional development of technology use with staff.”

Often, the decision for which classroom technologies were used was solely dependent upon teacher preferences. Survey respondents confirmed that “use of virtual learning, such as Google Classroom, was up to individual teachers” or “Tech access mostly depended upon individual teacher interest. If the teacher wasn’t interested, the kids in that room were not benefitting from tech.” Survey results also indicated that “use of online teaching tools needed some improvement.” Teachers needed more specific instruction in particular programs and methods for teaching and engaging students in learning through the online environment. In addition, “Teachers need professional development on how to implement technology, but first, they need the devices and bandwidth.” Another participant stated, “They (teachers) still need further training in how to implement technology in an effective manner.” Respondents also indicated the need for teachers to learn how to “better engage students through technology.”

Teaching and Learning Technology Status *During* the COVID-19 Pandemic

Responses to the questions, ***During*** *the COVID-19 pandemic, how would you describe your teaching and learning technology status overall? What can be improved?* were coded into the same four themes, *Learning Technology, Internet, Teaching Students, Teaching Teachers.* A fifth theme, *Learning Platforms*, was indicated through data analysis. A discussion of *Learning*

Platforms is included. Content analysis frequency and percentages are shown. Percentages are based on a total of 116 responses for this question. See Table 3.

Table 3

Themes from Teaching and Learning Technology Status Comments – During the COVID-19 Pandemic

Theme	n	%	Representative Comments
Learning Technology	37	32	"We did not have enough devices to be fully remote. We alos [sic] did not have video conferencing available."
Internet	36	31	"The availability of internet service for families was less than adequate."
			"The district is having to loan out WIFI hot spots in order for the student to access the instruction."
Teaching Students	21	18	"Teachers were using multiple platforms to communicate with students, we improved this by adopting Microsoft Teams and the single platform."
Teaching Teachers	56	48	"Teachers did not have experience and/or training in delivering remote services."
			"During COVID-19 teachers received more training on how to navigate platforms like ZOOM, Seesaw, Google Classroom, etc."
Learning Platforms	23	20	"We were using too many various platforms and programs. There was little consistency among teachers and families were asked to participate in numerous types of technology programs."

Overall comments for this open-ended survey question described how school districts were able to improve teaching and learning technology status during the pandemic. Districts supported teachers and quickly adjusted resources to get students and teachers 1:1 devices. One participant stated, "We grew leaps and bounds in our ability to use a variety of different platforms." A "steep learning curve" in the change is described by many as the change to distance learning occurred quickly and unexpectedly: "It has certainly improved but the curve of understanding is quite steep for staff" as well as "Teachers had a steep learning curve on how to suddenly deliver full-distance education." During the pandemic, survey participants described a persistent need for an adequate number of devices: "We need more computers and better access"; improved internet access: "The availability of internet services for families was less than adequate"; and training for teachers and students: "Teachers need training on how to create engaging learning opportunities for students." During the pandemic, previously existing inequities not only remained but also accelerated. Thus, teachers became acutely aware of the need to comprehensively support students. One participant voiced this representative comment, "It [the pandemic] revealed the inequities among students as well as staff. Some of our staff members didn't know how to conduct teaching online. We discovered we needed to offer professional development at so many different levels to get our teachers to a higher level of tech fluency."

Learning Technology

Rural educational leaders expressed concerns regarding learning technology as they reflected on their district or school situation during the pandemic. Many responses echoed the learning technology status prior to the pandemic. Those who struggled prior to the onset of the pandemic continued to struggle as they needed "newer machines" and "more machines." Students were "still having to share computers" as "we did not have enough devices to be fully remote . . . we also did not have video conferencing available." One respondent shared, "it was dismal . . . a district wide plan in place for technology versus letting it come from each building would have improved our response." The transition to online learning proved too fast for many school districts given the lack of internet access and low number of devices available to students and teachers.

Those educational leaders who described more effective use of teaching and learning technology during the pandemic shared, "We were not 1:1 before the pandemic but we are now." Another stated, "we have been fortunate and have good technology within our rural, 1-school district."

Prior to the pandemic, some schools were already positioned to support online learning. One educational leader said, "Prior to the pandemic, teachers were using multiple platforms to communicate with students, we improved this by adopting Microsoft Teams and the single platform." Twelve participants commented on the ability and commitment of teaching staff to pivot to online learning in a short time. These teachers were a key factor in student success during the pandemic. One educational leader's comment encompasses this phenomenon, "While we weren't prepared, my staff got onboard quickly. They created engaging lessons and made sure lessons were recorded so students who had to share computers could get materials when needed." Despite these positive reports, participants said they still needed more: "Digital lesson delivery and submission skills improved immensely. Staff are getting much better. Still have room to improve, for sure!"

Internet

Participants also reported internet access during the pandemic as unsatisfactory: "The status was nothing . . . we sent paper and pencil items home to students." Others shared, "our internet would go out frequently" and "a great number of students do not have internet access that is adequate for online learning." Connectivity issues for students were addressed through some of the following solutions: "The district is loaning out WIFI hotspots" and "local phone company provided internet service for the remainder of the school year to the few families that did not have service." However, these solutions were not completely reliable, nor did they provide equitable access for all students in the district. As these responses show, "Families without . . . internet are at a disadvantage" as well as "Wireless carriers do not provide solid signals consistently and when they do, they limit usage to small amounts that prevent online learning." Equal access to internet service remained poor during the pandemic.

Teaching Students

Teaching students during the COVID-19 pandemic was described as difficult at best. Several educators reported difficulties providing consistent instruction: "Too many programs and lack of standard expectations led to inequities in instruction. Each teacher was using something different and kids have to figure out how to use varying platforms." Others were somehow nimble enough to respond as quickly as needed. One district shared, "We are prepared to go fully virtual if we need to (again). . . . We have adopted Canvas online learning platform." The use of a common learning platform/learning management system (LMS) was determined to be the most effective approach for teaching students who were not able to attend brick-and-mortar schools.

The move to online learning and the speed with which it occurred was disruptive to both teachers and students. Most concerning was how to hold students accountable for their learning. When assignments were required to be submitted, some students were instructed to take pictures of their work rather than submitting a document to an online link. In an attempt to maintain an equitable learning environment for students with and without disabilities, teachers in some districts chose not to grade assignments during the initial phases of the transition. The sense was that those students with disabilities would not be able to achieve at pre-pandemic levels and districts did not want grades and advancement to suffer as a result. Responses noted, "We were not using technology to engage students and to hold them accountable for learning" as well as "Accountability was not written into the initial plans and students/families took advantage of it." In another strategy, some districts decided that any work students completed would only improve grades and a lack of work would not lower grades. One district reported, "students knew that their grades could only be helped and not hurt after shutdown. Most students stopped the educational process at this point."

In addition to the lack of accountability, student engagement online was reported as an overall challenge. Rural educational leaders clearly expressed that student engagement in online learning was dismal. Even when the internet was working correctly in schools and at home, student engagement declined. One response acknowledged, "Engagement is a huge component that was lacking last spring. It was very difficult to keep the classes attention online." Without students engaging in the lessons, showing up to live online class meetings, and completing work independently, learning slowed to nearly a standstill. Students did not have the experience and instruction necessary to use the classroom time and programs for learning effectively online.

Teaching Teachers

Teaching and learning technology status during the COVID-19 pandemic tells a story of committed and persistent educator: "While we weren't prepared, my staff got onboard quickly" and "When we were at distance-education, it was a steep learning curve for all. We taught teachers how to connect over video chat and most continued to teach with textbooks [sic] sent home and classes held over video. When not teaching students virtually, teachers were involved in online professional development to improve their teaching skills in the online environment." Daily problem solving included "how to handle technical issues from a distance" and instruction on how to record each lesson or class meeting to provide additional supports for those students needing more repetition and support. The training to improve teacher competency in the technology and programs needs to continue "to create engaging learning opportunities for students." The most successful report describes a collaborative approach: "We scaled up quickly and adapted very well. We put our teachers and support staff into expanded learning communities we called support teams. The tech experts in those groups helped the rest and everyone's expertise increased."

Learning Platforms

Learning platforms include online tools used to instruct, grade, and engage with students. Learning platforms used by the participants in this study included Google Meet, podcasts, video, live streaming, Zoom, Seesaw, and Google Classroom. Learning platforms also include learning management systems such as Canvas and Blackboard. Prior to the pandemic, technology use was based on teacher interest and competence rather than a mandated or necessary skill. This meant that "Teachers had a hard time learning to utilize Google Meet," and, "During COVID-19 teachers received more training on how to navigate platforms." During the shutdown, "The overall use of technology increased a lot."

The transition to online learning was unexpected and immediate. Therefore, software or systems used for instruction and grading *prior* to the pandemic were not always useful *during* the pandemic. Most often, different teachers or school grade levels were using different platforms. These differences created confusion for students. One educator reported, "We were using too many various platforms and programs. There was little consistency among teachers and families were asked to participate in numerous types of technology programs. We were not using technology to engage students and to hold them accountable for learning."

Finally, the pandemic created some permanent changes in the use of learning platforms in rural school districts. One educator wrote, "The district has now switched to Canvas as the delivery platform to help provide continuity in case of another quarantine." Another participant stated, "We moved our curriculum to online, so students are working on the same online curriculum regardless of where their physical presence is."

Provision of Special Education Services

Participants were asked, ***During*** *the COVID-19 pandemic, how have you provided special education services?* Responses to this question were initially coded by the researchers between *Did Not Provide/Incomplete Provision* and *Provided*. Those who *Provided* special education services fell into three types of provision: *Remote/Online, In Person/Face to Face*, or *Compensatory*. Compensatory refers to the provision of special education services outside of the regular school hours and as a remedy to not providing all the services or service amounts listed in a child's Individualized Education Program (IEP) as required by federal law (IDEA, 2004). Equity for all students, including those with disabilities, was a concern during the shutdown and one educational leader addressed this point, "During the first months of the shutdown, students (on IEP's) had optional, supplementary lessons provided online. A huge part of why it wasn't required was because it would be inequitable for our special education and ELL students."

Did Not Provide/Incomplete Provision

Two school district leaders reported, "We did not provide support for students with an IEP" and "We have been unable to provide these in any meaningful way since the inception of the pandemic." Two other school districts stated, "There was minimal one-on-one services provided by staff as the pandemic continued through the school year" and "not full minutes coverage." One of these district leaders mentioned working with their state department of education to "address these concerns." Participants did not report specific reasons for these decisions. However, one leader described underutilized supports for students with disabilities as "planning and collaboration for special education modifications and accommodations."

Provided

Most students with disabilities were served through remote learning using various online platforms like Google Meet and Zoom. Special Education teachers and rural Educational Service Agencies (ESA) scheduled regular online meetings with students with disabilities and their families to provide services and interventions. Materials outside of the online learning platforms were given as "take-home materials," or "paper pencil work picked up at school, done at home, and then dropped off at school." Another reported, "We also put together notebooks for younger students that had multiple activities for the students to practice skills at home."

In some cases, student IEPs were modified in the face of the pandemic. Educators were "contacting parents individually and setting up how to provide services based on the individual case." In addition, paraprofessionals were assigned to "virtually attend classes that our SPED students were in. Those paras then did virtual hangouts . . . to assist the students they were assigned to."

Those districts that provided special education services in person/face to face did so by completing home visits or setting up one-on-one or small group sessions between students and their service providers. One rural district leader said, "We had a few students (about 3%) that came into the school to receive face to face [sic] services." One educator stated, "Students can come in person to receive accommodations. Or they can be served through online learning." Two rural districts were supporting students on IEP's "as normal. In person" while another instructed "as normal but in limited numbers at a time."

Parent Feedback

Educational leaders were asked, *What feedback have you received from parents regarding online learning during the COVID-19 pandemic?* Out of 111 question responses, 51 were *Satisfied* and 76 were *Dissatisfied*. Of these responses, 23 included comments relaying both satisfaction and dissatisfaction. Those responses coded as dissatisfied included details on the experiences of *Parents Supporting Students* and *Technologies* in the home. Sixteen responses indicated parents wanted a return to schools as soon as possible. These responses were coded as *Return to Brick-and-Mortar Schooling*.

One comment was representative of most parents' sentiments: "the amount of mental stress on both parents and students was most telling." During the 2020–2021 school year, most communities were in "shutdown" where workers and students remained at home. Parents worked online from home, and children learned online from home. There was no escape from the pressures of any aspect of life—work, parenting, schooling, and more all occurred in one place.

Satisfied

Parents who communicated satisfaction with learning during the pandemic (51) expressed gratitude and support for their educators and the sudden online learning needs as expressed here, "Most of our parents have been supportive of the effort performed by our teachers." Another response stated, "Parents (for the most part) thought teachers went over and above to meet the needs of students." Regular consistent communication with families appeared to be vital to parent satisfaction with online learning. As one response showed, "Consistency was key! Teachers and kids were online daily at the same times. Parents received emails with information for the week, kids received daily communications through Google Classroom." As a result, "Parents have appreciated the efforts we have made. They have been supportive partners."

Dissatisfied

The primary concern of *Dissatisfied* parents during the COVID-19 pandemic was their ability to support their children's learning at home. A substantial number of responses (76) showed that parents were dissatisfied with online learning for their children. One response describes this struggle: "They hated it. Kids were off task and parents were trying to work while trying to also help their children." The challenge for parents was "maintaining jobs and teaching/watching their children" as "it was hard for them to juggle the at-home learning with their work schedules." In addition, parents "feel completely unprepared to assist their children in online learning." Responses indicate parents had difficulty "getting their children to access and engage in the learning" and "take the learning seriously." One participant shared, "as time progressed it became harder and harder to keep students engaged." In one school district, parents had a hard time getting students to consistently make progress on their work. Eventually, "students wore the parents down and parents got tired of fighting with the student, allowing the student to disengage."

A few parents "weren't cognitively able to support their students." The level of work their children were expected to complete was beyond their "skill-levels." Others said the work was "too easy and there wasn't enough work" as their children could "finish it very quickly." Another response sums up a common sentiment that "Many parents felt that the older students were just given busy work and did not learn the standards. The parents of younger students were upset that they received too much work and couldn't get it all completed." Two responses specifically commented on a need for more rigor in the content and learning as stated, "They (parents) are unsure that we will be able to deliver a more rigorous program," and learning "needs to be more rigorous." Finally, one participant reported, "We did have many questions in regard to how we were going to help students with IEP's." This same participant discussed working daily to improve services and instruction for those students on IEP's.

Technologies

Parent feedback responses coded as *Technologies* refer to parent experiences with the technology available for their children's online learning. Responses also refer to the equity umbrella theme. Thirteen responses included details about technology use and difficulties for parents, families, and students online learning. Ten of the thirteen responses refer to internet access as the primary challenge. Most telling were the comments: "Families without internet or a device were at a disadvantage" and "Some families never receive internet access—too rural." Another noted, "internet access in my school is a huge challenge. It is terrible." Other participants stated, "We had multiple families that lacked internet and electronic devices. Also, many homes only had one electronic device, but multiple people needed to use it each day," and, "In our rural area, internet connectivity is limited—when there's more individuals per household online, the service is slower." Some families chose to use phones to access the material; however, "programs were more difficult to operate on phones than computers." For those districts that provided devices (laptops, Chromebooks, tablets) to families as evidenced by "Families have also been leery of bringing home expensive computers that they do not trust their students to care for. . . . Our district is implementing a technology fee for broken equipment, but with 70% free/reduced, most families will not pay the full fee."

In addition, not all parents felt confident or competent with the technology used for online learning. As responses show, "Parents did not feel comfortable being the teacher" and "parents are not able to facilitate learning because of skills or work requirements." Some participants felt parents needed more support in the online learning environment, identifying that "Parents/guardians need more training regarding technology and how to access the various devices/platforms, etc."

Return to Brick-and-Mortar Schooling

Of the 16 responses describing parents' desire to move back to brick-and-mortar schooling as soon as possible, "most were ok with it on a temporary basis." Reponses showed, "They (parents) appreciate our district's response however they want their kids back in school because they have to work." One response addressed the parents' lack of confidence in supporting their children's learning: "They have stated they are not teachers and have not been exposed to the material that is expected to be taught to their children."

Limitations and Future Research

One limitation of this study was its geographic focus on the central and western United States. Additionally, the sample size was small, and it was based on the willingness of state departments of education to provide access to their email lists. The state of mind of rural educational leaders must also be considered as a potential limitation. At the beginning of the 2020–2021 school year, educational leaders were likely overwhelmed with issues related to keeping districts and schools running during the COVID-19 pandemic. Rural educational leaders' time was at a premium and completing a survey was likely low on their priority list, so responses might be more limited than under more normal conditions.

Opportunities for future research include multiple areas of investigation. Although schools are no longer operating in a strictly virtual mode, future studies can evaluate rural educational leaders' perceptions of how the COVID-19 pandemic has changed the teaching and learning environments in their schools. Further investigation is necessary to discover any long-term effects of the COVID-19 pandemic on the learning of students with and without disabilities. We also need a greater understanding of how students with disabilities can be better served with online technologies, especially when considering specific disability categories. Further research will provide a better understanding of potential regression in student learning, especially in rural areas where schools and parents struggled to stay connected. It will be important to understand which changes to virtual instruction, temporary or permanent, have been most helpful or detrimental for student learning. Having a more complete understanding of how online teaching and learning technologies can best be applied to brick-and-mortar schools is also essential. Future studies must also identify how to provide the most effective professional development for teachers who may struggle with adopting teaching and learning technologies into their own instructional repertoires.

The COVID-19 pandemic also required parents to become more immersed in their children's learning. To better support parents in the future, we need to investigate the perceptions of parents regarding their insights on how to better engage their children's learning at home.

It is also essential that we continue to study the availability of broadband connectivity for schools and families in rural settings. Understanding more clearly the implications of poor broadband access on student advancement in rural areas will support efforts to change state and national policies and influence decision makers as they consider how to best improve internet access for all Americans.

Conclusions and Implications

The COVID-19 pandemic tested the mettle of students, parents, teachers, and educational leaders for their ability to quickly adapt to abruptly changing conditions. In a few short months in 2020, millions of students transitioned to learning online rather than in their traditional brick-and-mortar schools (National Center for Education Statistics, 2022). The current study provides a unique snapshot of a critical juncture during the fall of 2020 as the impacts of the pandemic on rural schools were being fully felt. This study investigated rural educational leaders' perceptions of the effects of the pandemic on teaching and learning prior and during the crisis. The study also provides insights on issues related to providing special education services in virtual settings and parent reactions to how the pandemic affected their children's learning.

The pandemic focused brightly the light of inequity for teaching and learning in rural settings. The digital divide affecting the connectivity of rural areas has been a known issue for decades (e.g., Hindman, 2000; Rooksby et al., 2002), yet it persists. Bandwidth reliability issues in the fall of 2020 affected both schools and homes as children tried to continue their educations (Kormos & Wisdom, 2021). Some rural schools struggled to maintain connectivity to their students while families in outlying areas tried to remain connected to schools (Jacques, et al., 2021). Insufficient broadband connectivity caused some students to be left behind (Pitluck & Jacques, 2021). Yet, not all educational leaders in the current study reported difficulties with teaching and learning technologies, though the data revealed that these instances were not as common.

Educational leaders provided insights into some of the issues related to the quick pivot to online learning. Prior to the pandemic, some leaders described technologies that were underutilized and that the limited use was often due to teacher comfort or knowledge of the available technologies. Leaders also expressed that teachers needed additional teacher training in the use of internet technologies. Issues related to the forced use of relatively unfamiliar technologies and the lack of essential technological learning tools became more evident as COVID-19 dictated how students accessed curricula (Pitluck & Jacques, 2021). Additionally, educational leaders emphasized the fact that some districts had not been investing in online technologies including devices and software due to lack of funding. Providing teacher training and ongoing professional development will help to ensure the effectiveness of teaching and learning technologies as districts seek to improve their investment in teaching and learning technologies (Caglayan, et al., 2021).

Schools and districts struggled to support students with disabilities during fall of the 2020–2021 school year (Jameson et al., 2020). According to the perceptions of educational leaders who participated in this study, students with identified disabilities may not have been receiving special education services according to their IEPs. It was reported that some students with disabilities received fewer or no special education services. In some cases, services were provided face-to-face even though schools were shut down. One educational leader even stated that schools in their district provided parents with the option to bring their child to the school or to just receive services online. Though which online special education services were available were not described by respondents in the current study. To overcome the IDEA (2004) service provision requirements, some student IEPs were changed. This insight begs the question of what special education services were reduced or eliminated. Additional research would be helpful for understanding how students actually did receive virtual services during the pandemic.

According to the educational leaders who participated in this study, parents communicated frustration as they attempted to keep their children engaged in the learning process. Parents were concerned with not only keeping up with the responsibilities of their jobs but also with the education of their children at home. Furthermore, home internet access was often described as compromised by multiple users each trying to use limited or nearly nonexistent bandwidth. Parent sentiments also echoed that face-to-face instruction was preferable to virtual teaching and learning. Educational leaders described the grateful feelings of many parents while also acknowledging that many parents were disturbed by the lack of consistent education that their children were receiving.

Yet, the umbrella theme of this study was that of equity. Rural educational leaders expressed that not enough was done to support all students equitably during the pandemic. They lamented that remote learning opportunities have been identified for years as important equity issues. In 2019, the Federal Communications Commission (FCC) attempted to evaluate the broadband deployment for communities and schools in the U.S. (FCC, 2019). One of the most telling statements of the report was “Although we agree . . . that our fixed speed benchmark must continue to keep pace with consumer usage, demand, and technology, the definition of ‘advanced’ telecommunications capability in section 706 nowhere suggests that ‘advanced’ necessarily means the highest quality service possible.” Clearly, an equity gap for broadband service in rural schools will remain for the foreseeable future. Equity issues in the current study included access to broadband internet, student devices, and teachers fully trained in online instruction.

Limited broadband in rural areas is only part of the equity issue. Rural schools struggle with budgets for many necessities (Tieken & Montgomery, 2021), including teaching and learning technologies (Kormos & Wisdom, 2021). Moreover, family poverty is a real and constant issue in rural areas (Dobis et al., 2021). Families should not have to decide between providing basic needs for their children and paying for internet access so that their children can continue learning. When students do have access to broadband internet, there are some technology options that provide important opportunities. Web-based document software (e.g., Google Docs, Microsoft Office Online, etc.) may provide more equitable access during online learning. Some web-based solutions may also provide students with valuable opportunities for online collaboration. Learning management systems may also provide more consistency when online learning is provided.

Twenty-first century teaching and learning requires greater investment in technologies for all students to access the general education curriculum even beyond the limits posed by the current pandemic. It is essential that rural schools are provided equal opportunities to meet the learning needs of students with and without disabilities through the application of appropriate teaching and learning technologies.

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About the Authors

Todd H. Sundeen, PhD, is an associate professor in the School of Special Education, College of Education and Behavioral Sciences, at the University of Northern Colorado. His primary areas of specialization are inclusive practices and co-teaching especially in rural settings. He also focuses his research on instructional interventions for students with intellectual and developmental disabilities with a specific emphasis on classroom learning strategies, interventions, and assessments for mathematics and expressive writing.

Michelle Kalos is a doctoral student in the School of Special Education at the University of Northern Colorado. Her research includes post-school transition, self-determination/self-advocacy, and rural education for students with disabilities. She has a Master's in Special Education: Deaf and Hard of Hearing. She has worked as a Special Education Teacher since 2006.

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Building a Virtual STEM Professional Learning Network for Rural Teachers

Julie Thiele, *Wichita State University*
Ollie Bogdon, *Missouri Western State University*

This study explored the experiences of rural and suburban teachers as they engaged in virtual and hybrid STEM professional learning opportunities, analyzed through an ethnographic case study. Provided are two lenses through which to view the findings. First, from the rural teachers' perspective, an exploration of the experiences while engaging in virtual and hybrid STEM professional learning, with findings indicating three major themes: 1) increased collaborations, 2) equitable access to resources and learning and 3) increased content and pedagogical content knowledge. The second perspective, from the project leadership, as collaborations across two IHE's and with multiple district teachers and administrators, led to the design of a professional development model that was successful at initiating a network for rural teachers to engage in STEM learning through investigations, collaborations within and between districts, and coaching activities, aimed at increasing STEM content knowledge and pedagogical content knowledge.

***Keywords*: rural teacher development, professional development model, science education, STEM education, online professional learning communities**

> In terms of professional development, this project is a testament that we do not have to be alone, nor do we need to reinvent the wheel. We have such talented and knowledgeable people within all districts and universities, small and large, across the state and with projects like this, we can virtually connect and learn from one another. State and district initiatives tend to dictate a building's professional development agenda; however, I feel the quality of experiences provided to teachers would be stronger if we were to collaborate when it comes to planning, preparing, and delivering professional development opportunities. - Rural STEM Teacher Participant

Teachers and administrators from districts, rural and suburban, collaborated with professors and instructors from institutes of higher education (IHE) to participate in two summers of a 2-week professional learning and 1 school year of instructional coaching, through hybrid and virtual participation. A case study research design was foundational to the research-based approaches employed including: (a) intensive summer institutes during which content and pedagogy were directly addressed through book studies, investigations, and discussions, and participants were also charged to design and establish an action plan with input and support from their building/district administrators; and (b) follow up activities, including classroom-based coaching experiences, progress monitoring of actions plans, staying connected with grade level and content specific teachers, along with planning and leading professional learning for their districts.

This project was conducted through collaborative partnerships of two IHEs, a large public land-grant university and a small private Catholic university, along with 10 school districts from across the state of Kansas representing rural and suburban districts and isolated STEM teachers to assess effective ways of providing equitable access in STEM professional learning opportunities for rural and isolated educators. Two of the districts were classified as high needs, all received title one funding, and all the districts fell into one of the following categories: single building rural district, multiple building rural district, multi-town rural district, single campus rural district, suburban district, and private religion-based district. The study was funded through a Mathematics and Science Partnerships (MSP) grant award (KS 84.366B from the S366B150017 federal award) funded through the U.S. Department of Education and was composed of K-8 grade teachers and administrators.

Literature Review

As STEM exploration and career fields continue to grow in interest, there is a looming gap between urban and rural opportunities for STEM learning in the classroom. Lakin et al. (2021) share potential reasons for rural students' lack of interest or enrollment in STEM fields, including lack of familiarity with STEM occupations, less industry outreach, fewer college STEM prerequisites offered in high school, and lack of job potentials in their rural area. Yettick et al. (2014) describes five major areas of challenges for rural districts to engage in STEM learning, including funding, staffing, flexibility, local services, and professional development. With these many challenges comes the call for IHEs to collaborate with districts, of all types and sizes, to engage in high-quality STEM professional learning.

Subotnik et al. (2011) found that the sooner children can be provided with STEM learning opportunities, the more likely they are to pursue a STEM career, which identifies the need to train elementary and middle school teachers. Rather than attempt to train STEM teachers and import them into rural districts, Barret et al. (2015) described the benefits of utilizing partnerships to provide specific and STEM targeted training to teachers already positioned in rural districts. Lavalley (2018) reiterated the importance of training teachers in their rural locales but extended this idea to describe the challenges of attaining access to universities or other training providers to develop and implement these trainings as fewer rural teachers participate in STEM professional learning than their urban counterparts. In their study of teachers' perceptions of STEM in rural settings, Goodpaster et al. (2012) found teacher professional growth as a major barrier in terms of the lack of access to and affordability of high-quality STEM professional learning opportunities.

This inequitable access to STEM professional learning opportunities has led to the utilization of virtual learning platforms to engage rural and otherwise isolated teachers, including teachers who may not have a content or grade-like colleague within their district or geographical region (Duncan-Howeel, 2010). These virtual platforms allow teachers to remain in their rural locations, without the added financial and familial stressors of leaving their school community, or even their personal homes for professional learning, but these virtual platforms must be utilized effectively. Herbert et al. (2016) note multiple studies have shown important factors that increase the effectiveness of online professional learning, including content specificity, hands-on features, extended length of time, and cycles of feedback and reflection. Durr et al. (2020) concluded at the culmination of their professional learning community study with rural districts that online professional learning led to higher teacher efficacy and the desire for continued networking and growth. The project overview will describe how researchers utilized hybrid and virtual attendance platforms to form a network of teachers, rural and suburban, throughout the state and engage teachers in high-quality STEM professional learning.

Project Overview

The planning team who brought the vision of this project to fruition consisted of IHE STEM content faculty, education pedagogical faculty, instructional coaches, and administration from three of the participating districts. This team collaborated to maximize their internal and external assets to overcome the challenges facing rural schools in receiving quality STEM professional learning and to address the three grant project goals: 1) Increase teacher content knowledge in mathematics and science instruction, 2) Increase student achievement in mathematics and science, and 3) Increase IHE and LEA collaboration to develop a statewide MSP model. This article is focusing on the third goal from the grant project. Using grant funds, Swivl robots were purchased and distributed to each site location based on need. Each site was responsible for having a compatible iPad or phone to use in the Swivl. The tracking and multiple microphone ability of the Swivls allowed for better video tracking of the lead presenter and multiple small group audio captures, when small group discussions or investigations occurred. All sites kept their Swivl microphones off during presentations until they had questions, in which case they turned on their Swivl microphones to pose their questions. For year two, the presenters used inexpensive Bluetooth headsets that provided better audio quality for broadcasting to all the virtual sites. Virtual sites continued using the Swivls and their audio microphones to capture activity and audio. The only drawback when using the Bluetooth microphones was capturing teachers' questions or dialogue in small group work. When face-to-face participants asked a question, the headset was handed to them to talk so all the virtual locations could hear or the facilitator simply repeated the question.

Purchasing expensive technology is not necessary to deliver high-quality virtual and hybrid professional learning. Using existing technology resources within the schools and universities, and a minimal investment in peripheral devices, such as Bluetooth microphones, may be all that is required for each hybrid and virtual location. Using a Bluetooth microphone connected to desktop computers with an attached camera or existing tablets or laptops would be sufficient. Using more mobile camera devices provides easier movement to provide up close views of what presenters are demonstrating or small virtual groups providing close views of their progression through the investigations. Professional Zoom accounts were necessary, but the universities already had this technology resource, so there was no additional cost for Zoom accounts.

Well in advance of the summer institute start date, dedicated time was necessary for extensive and thorough logistical and content planning if equitable access to high quality/high rigor professional learning was to be achieved for these rural and isolated STEM teachers. While working with the planning team and synthesizing the results of the teacher application forms, IHE principal investigators directed talent and resources to best meet these rural and isolated teachers and their district/school needs. All lessons and investigations had to be identified or written up with a complete list of materials and supplies needed to carry them out, allowing enough time for purchasing and delivery of supplies and materials to all virtual and hybrid sites. The number of teachers in each book study breakout session also had to be identified, allowing time to receive and disseminate to the correct teacher location for the summer institute.

Five major components comprised the summer institute: book studies, content presentations, investigations, pedagogy presentations, and networking/collaborative team action planning time. In addition, this project included school year coaching for all participants. The coaching was delivered face-to-face, virtual, or a combination of these modes. Each IHE region had an instructional coach to support the teachers and administrators in implementing their district action plan and reinforcing the content and pedagogy for individual teachers.

Planning and Set-up Phase

Using Good Pedagogy for Deep Content Delivery: IHE Science and Math Departments Working with Education Departments Pedagogy Experts

When working with the IHE content faculty, care was taken to ensure all were using best STEM pedagogical practices. Faculty specializing in science and math pedagogy and instructional coaches were paired with content faculty to work as a team to create the needed delivery components. The program began with a whole group meeting designed to ensure everyone understood the project expectations so as to maintain a non-threatening team atmosphere and minimize the potential for bruised egos. Paired group meetings followed to gently guide and support the use of desired pedagogical practices when teaching content at the summer institutes. For instance, the researchers needed to ensure the STEM professors embed the Science and Engineering Practices and Standards of Mathematical Practices in their presentations and that they were well aligned to the goal of a particular session. If the STEM professors were struggling with how to dig deeper into the day's assigned content by avoiding using lectures and instead incorporating interaction with the hybrid and virtual groups, the pedagogy professors and instructional coaches were available to help brainstorm.

Ensuring District Administrative Buy-in and Follow Through

For teachers and districts to participate in this study, administration support had to be secured. Prior to the summer institutes, the principal investigators met face-to-face or virtually with district superintendents to secure their support for their teachers implementing the action plans for the building/district and identifying the appropriate administrator to participate in the required summer institute administrator meetings to help guide the design of their school year action plan. District administrations were also requested to meet with participating teachers to create a working list of possible action plan district and/or building needs so district groups would have a place to start during team meeting time.

Virtual and Hybrid Physical Site set-ups

Prior to the start of the summer institute, each location was delivered the correct book study materials for the site and received identical tubs of required supplies for each session and necessary paperwork. In addition, for each site, rooms were identified for whole group sessions; 2 content specific sessions (set up for small group interactive investigations and hands-on learning with manipulatives or models); and multiple book study rooms (depending on how many rooms were needed.)

For the larger gatherings, whole site groups, or large content groups, rooms already equipped with overhead projectors were selected. Depending on the number of teachers at a given site in the same book study, breakout rooms might vary from those already equipped with overhead projectors, or smaller rooms with a television, or a small room where a site singleton in a specific book study could use their own laptop for audio and video. All other rooms were equipped with at least one video camera and audio set-up. Rooms in which content or pedagogy were being presented had a two-camera set-up, one toward the front capturing the “instructor’s view” and one towards the back capturing the participant’s view. Only the front camera set-up was activated for audio and video in Zoom. The second camera was video only.

There were many options of how to handle technology logistics. First, we ensured every site had a tech knowledgeable participant, or on-site tech support should there be a glitch. The following are low and higher budget options for setting up the hybrid and 100% virtual locations. For the summer institute, the face-to-face rooms were set up with at least three screens: 1 to broadcast the presenter and their face-to-face group, 1 to broadcast the computer of the presenter, and 1 to broadcast the virtual groups joining the presentation. The virtual locations also had a 3-screen set-up to broadcast the presenter, their computer, and the third screen to show the virtual groups participating. The face-to-face and virtual sites had all the hands-on materials on site to complete all activities. A site facilitator was present to assist in delivery and dissemination for all presenters.

Delivery and Interactions

As can be seen in the sample schedule in Figure 1, Monday through Thursday morning sessions, included the science and math groups having independent deep content sessions hosted by IHE faculty. Virtual sites along with the hybrid sites moved to assigned physical rooms where the respective Zoom room was set up to deliver either the ‘deep content dive’ broadcasts. Throughout the day, teachers at the hybrid sites hosting their content area sessions/book study were face to face with the instructor as the broadcast being virtually transmitted to all other sites across the state of Kansas. Following a short break, teachers went to their assigned physical room where their book study (STEM/math/science) would be received virtually or face to face. This same practice was followed throughout the day for the investigation and pedagogy blocks. The morning welcomes/check-ins and afternoon wrap-ups/closure were a simultaneous broadcast from hybrid site one or two or tag teamed between the two sites at times.

Coordination of the content delivered in these sessions occurred through the lead planning team and the summer institute planning team. Hybrid site 1 took the lead with mathematics, and hybrid site 2 took the lead with science content. Both institutions worked collaboratively on all content and pedagogy delivered. To assist in building the learning relationships between concepts and procedures during the summer institute, IHE Math and Science faculty co-developed and delivered content with education staff to better model best practices and look at the bi-directional, causal links between conceptual and procedural knowledge. Most IHE content faculty have limited familiarity with K-12 content and practice standards. Through co-developing and delivering in the summer institute, not only did teacher participants experience better modeling of teaching best practices, but IHE faculty also enriched their teaching methods repertoire.

Figure 1

Sample Day's Schedule with Five Components

	Check-in/Welcome	
simultaneous	**Science Content Presentation**	Motion and Energy Transfer relating it to yesterday's investigation: Crooked Swing Pendulums investigation
	Math Content Presentation	Binary & Place Conversion
simultaneous	**Book Study** K-5 science & STEM	Science: Foundations of 3-Dimensions
	Book Study 6-8 Science	Video link on using Models
	Book Study Math breakout groups varying by grade or topic	Math K-2 Book Study Math 3-5 Book Study Math 6-8 Book Study
simultaneous	**Science Investigation**	Investigation Sink or Float
	Math Investigation	Kodable & Scratch Setup
	Lunch Break	
simultaneous	**Pedagogy /SEP's**	Conducting Investigations and Transforming Your Classroom • Asking Questions • Developing and Using Models • Constructing a Mental Model • Developing a Predictive Physical Model
	Pedagogy /SMP's	Teacher Practices: Elicit & Make Use of Student Thinking
Groups	**Vertical/Content Team Meetings** or **Team Action Planning**	Some days could be all one/other, or split 50/50 between: Vertical team meetings e.g., all 5th grade teachers meet in same Zoom room, or breaking into specific science content rooms, ***and/or*** Team Action Planning time
	Wrap-up/Closure	

Monday through Thursday afternoons included the pedagogical block, allowing teachers opportunities to reflect on how their morning content and investigations integrate with pedagogical best practices. In preparation for both Fridays of the institute, Monday through Thursday afternoons included dedicated time for each district/school team to work on their sustainability plan to further professional learning for their peers/school/district. On Fridays, school teams met with their school/district administrator(s) who attended the institutes for the day. During this time the teacher teams worked with their respective administrators to finish building and gaining approval for the implementation of their plan. It was expected each district team would build professional development appropriate for their setting and deliver it during the school year. The IHE instructional coaches as well as the IHE pedagogy faculty played an integral part in following through on this component. Friday sessions of the summer institute helped lay the groundwork to accomplish grant goal 3, to build networks of teachers within and between districts throughout the state, specifically continuing to build relationships between rural isolated teachers and their colleagues teaching similar grade levels and content.

When looking at Project Excel's success of creating high-quality professional learning using technology as well as building a virtual STEM professional learning network for rural teachers, 4 cornerstones underpin its strength: (1) delivering pedagogical content knowledge to ensure best pedagogical practices are being used when delivering content; (2) using investigations to reinforce STEM content through hands-on activities and anticipate student thinking, including misconceptions; (3) coaching during the summer institutes and throughout the school year to support individual teach growth as well as support the implementation of their action plans; and (4) collaboration among the teachers, building a virtual STEM professional learning network for collegial support and access to content and pedagogical professors striving to bring equity to Kansas's rural and isolated teachers.

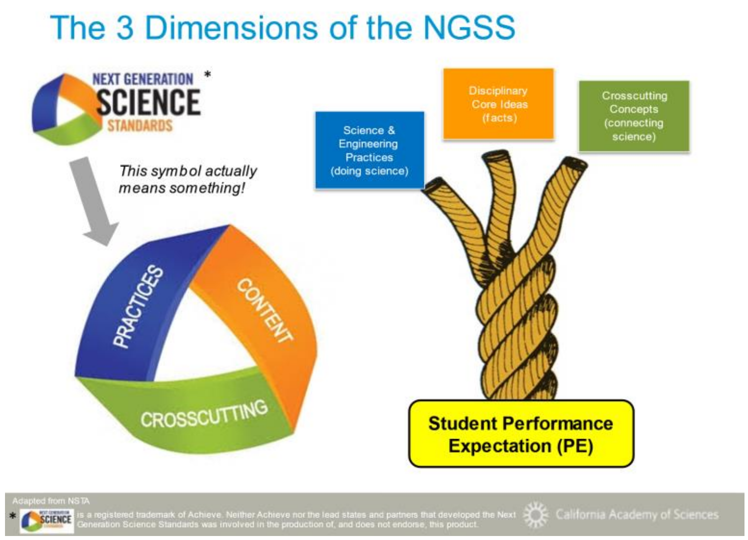
Pedagogical Content Knowledge

STEM faculty and instructional coaches provided learning opportunities using a mix of grade level standards from Next Generation Science Standards (NGSS) and or Common Core Math Standards. The science content area will be further explored as we continue outlining delivery and interactions. From a pedagogical viewpoint for science, we chose to focus on the Three Dimensions (3D's) of the NGSS. "Within the Next Generation Science Standards (NGSS), there are three distinct and equally important dimensions to learning science. These dimensions are combined to form each standard—or performance expectation—and each dimension works with the other two to help students build a cohesive understanding of science over time." (NGSS Lead States, 2013). Figure 2 provides additional details on the 3D's that were explored and embedded throughout the project.

When teachers completed their applications to participate, they indicated their familiarity with the 3D's. Teachers entered the summer institute with a significant gap of knowledge and understanding. Experiences ranged from never having heard of the 3D's, to a solid cluster who had heard of the 3D's but had no idea of their use, and only a single teacher already teaching students with the 3D's embedded into her teaching. These were not surprising findings given the isolation and challenges rural districts face in trying to stay current within their discipline (Yettic, et al., 2014).

Figure 2

The 3 Dimensions of the NGSS



The primary goal of the pedagogical content knowledge component was to help teachers understand and use science progressions effectively for grade levels before and after the grade they teach. To facilitate learning these necessary content and pedagogical teaching skills, teachers would engage in an investigation facilitated by an instructional coach or professor specializing in pedagogical methods. The university science professor would also attend and observe the teachers doing the investigation, noting any misconceptions, and gaining insights into their thinking about the concept. The following morning, the science professor used discussions and demonstrations to correct misconceptions noted and then expanded and dug deeper into the investigation content from the previous day. Using the matrix of progressions for DCI's, SEP's, and CCC's (NGSS Lead States, 2013) helped build consistency in content delivery and guided their own preparation and discussions with teachers. For example, in the Crooked Swing investigation, scientists presented Motion and Energy Transfer content from the investigation that teachers previously explored and then provided time for participants to ask clarification questions to increase science content understanding and dig deeper into the concepts the investigation afforded. Figure 3 shows teachers interacting virtually, through the use of Padlet, with scientists regarding the investigation, with a focus on Life Science and SEP's.

The book study also proved useful in developing pedagogical content knowledge. When teachers applied to participate, they selected one of several STEM book study options in which to participate. Each day's book study block started with a short presentation from the group leader, either an instructional coach or professor or in summer 2 from teachers taking a leadership role and leading book studies. The presentation was followed by a whole group discussion and ended with group work and/or additional reading assignments for the next day. With several book study options and multiple teacher locations, having a master schedule for all presenters, a master schedule for all locations, then individual locations increased time efficiency. Figure 4 outlines how the hybrid and virtual teachers navigated in Zoom rooms and physical rooms at their sites and who was responsible for facilitating each session.

Figure 3

Padlet Virtual Collaborations

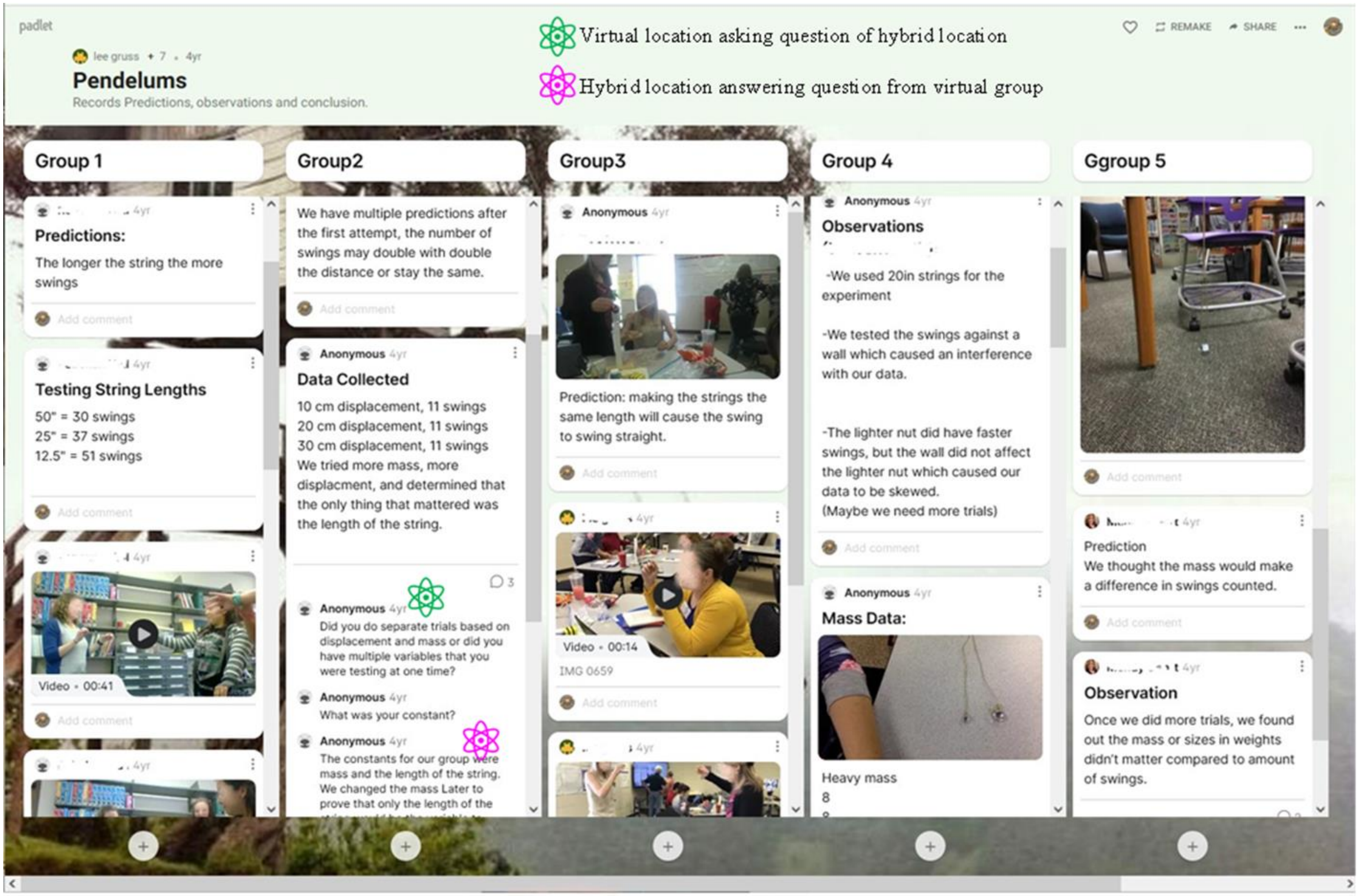


Figure 4

Planning Responsibilities and Content Delivery Locations

	Planners	Facilitators			
Activity Description	**Planning Staff**	**Hybrid Location #1 Math**	**Hybrid Location #2 Science & Engineering**	**100% Virtual #1 Site***	**100% Virtual #2 Site***
Check-in/Welcome	All	Grant PI's-Live Feed			
Dig Deeper Content/Concept Presentation	IHE professors & Instructional Coaches	Math content & concepts	Science content & concepts		
Book Studies	All	See Breakout Schedule		Science 6-8 (2nd year)	
Investigations-new content/concept	IHE professors & Instructional Coaches	Math content & concepts	Science content & concepts		
Closure		No Live Feed - Facilitators discuss morning debrief and afternoon schedule then dismiss to lunch			
Lunch	Everyone on their own				
Pedagogy Presentation	All	IHE professors and/or Instructional Coaches	IHE professors and/or Instructional Coaches		
PLC/Team Time	All	Grade Level Teams - All Facilitators - Live Feeds for Each Grade Level/Content Area			
Wrap-up/Closure	All	Grant PI's			
* Blank spaces indicate live feed participation, no facilitation roles at site.					

Investigations

We will use science to illustrate project procedures as we move forward. The day prior to each science investigation, teachers were provided grade specific content reading to review in preparation for the investigation. Specific DCI performance events for investigation content were also included for the teachers. Many of the investigations used during the summer institute were adapted from the *Learning Science by Doing Science* book, allowing a take home reference to encourage their deepening of understanding the NGSS. Each location, whether 100% virtual or hybrid, were provided identical materials for each investigation. Participants from across the state would listen virtually to instructions provided by the facilitator, then all sites would begin their investigation. While all sites were engaged in the investigation, they muted their mikes to allow other sites chatter not to distract them. The IHE site facilitator continuously checked in with all the virtual groups and their face-to-face group to ensure all were proceeding well or to ask a probing question to a particular site to help nudge them in a better direction. When a site had a question, they would simply unmute their mike and pose their question to the facilitator.

Small site-based groups of teachers were formed to complete investigations. They used traditional hard copy notebooking practices to log all aspects of the investigation as well as make note of arising questions. A virtual cloud-based application, Padlet, was set up for each group to use simultaneously with their traditional hard copy notebook. Using Padlet allowed simultaneous sharing from all teachers across the state of Kansas. Teachers might post text descriptions, pictures, or even upload video clips as they progressed through the investigation. Padlet also enabled teachers to pose questions or leave a comment on what their distant colleagues posted as shown in Figure 3 above. Facilitators encouraged using this resource as a form of digital notebooking to promote site to site collaboration and sharing of teacher thinking, their own Ah-ha moments, and even their corrected misconceptions which their students may also embrace.

Time was always dedicated at the conclusion of the investigation for sites to share their observations and findings and then discuss misconceptions or anticipated challenges with their students. All sites shared and offered opinions. Each site had poster-size descriptions of all the SEP's from the NGSS. Using the Post-It notes on their tables at each site, teachers were asked to identify which practices "could "work with the investigation they just completed, and which one practice was the strongest for the investigation they just completed." The sticky notes were then placed on the respective SEP posters. A collegial discussion usually ensued as teachers throughout the sites turned on their microphones when it was their turn to share. The process on day one of the institute when SEP's were introduced for some and reviewed for others and teachers discussed in depth what skills of doing science were revealed in each SEP set the stage for these later discussions. The first thing the following morning, STEM professors would reflect on their observation of the teachers completing the investigation from the day before and then move into digging deeper with the major science concepts and relevant DCI's across grade levels for the investigation

Coaching

An instructional coach from each of the IHE regions collaborated with the IHE faculty to provide ongoing support to teachers throughout the school year. These coaches worked closely with their designated teachers throughout the summer institute to begin forming a bond. Ongoing job-embedded training has significant impacts on teachers' efficacy and improving implementation of learned effective teaching strategies (Cobb & Jackson, 2011). Glover et al. (2016) further elaborated on the effectiveness of sustained professional learning with rural teachers. Providing this year-long coaching afforded the teachers to further integrate the summer professional learning with school-year application. Coaches collaborated with building or district administration to assist the implementation of action plans for the project participants, collaborated with participants and administrators to provide professional learning within each building or district and build relationships with building or district teachers outside the project.

Teachers from virtual sites used recording technology and Zoom video conferencing and recording to conduct lesson observations and have follow-up feedback sessions when in-person communications were not possible. Enacting a cycle of joint planning sessions, building on their plans generated during the summer institute, enhanced coaches, face-to-face or virtual, preparedness for observing throughout the school year as teachers implemented their lessons. Special care was taken by the coaches to analyze along with the teacher and how their NGSS-DCI performance event from their lesson was supported through a purposeful relationship to the selected SEP's and CCC's.

Collaboration

Within District. School/District Professional Learning was designed to complement summer institute content and address concerns identified through ongoing evaluation of coaching sessions with the teachers. "Various platforms were utilized by PD leaders and teachers to form networks of teachers by school, district, content area, and grade level. In many cases, the teachers in this project, from rural and geographically isolated areas, may be the only teacher that is accountable for specific content in their building or district" (Thiele & Bogdon, 2020).

Details of what this professional learning looked like varied depending on individual school/district needs. Instructional coaches assisted, virtually or face-to-face, in the development and delivery of these opportunities as needed. Teachers were encouraged to lead these opportunities by themselves, with their school institute team, or co-teach with teachers from other districts based on readings from DuFour & Reason (2016) on the effective principles of virtual professional learning communities (PLC) and the development of these collaborations. Depending on a district's culture, some teams were better received if led by a teacher outside the district rather than an in-district leading the team. School/district professional learning included learning the relationship between concepts and procedures as experienced during the summer institute and center around appropriate performance expectations. When teachers better recognize and understand the conceptual understandings and procedural fluencies in the standards they teach, they will be better prepared to establish goals to focus learning on the standards, to support students by identifying their deficiencies, and using discourse to make explicit how students can build procedural fluency from conceptual understanding.

Across State. The afternoon meetings during the summer institute included time for teachers to not only meet in their district groups but also to meet in grade and content groups. These groups began developing a network and framework for a grade/content PLC network across the state to help support the singleton/isolated teachers and schools. While district teams could also dialogue through this same system, the importance of providing a professional support network for the singleton/isolated teachers and schools was the driving force. This grade/content state-wide PLC dedicated support time during the Summer Institute's was also complimented through introducing the science teachers to the National Science Teaching Association (NSTA) virtual learning community. Only 2 of the participants were aware of this resource, and only 1 was an active user. While many of the resources on the NSTA site can be used for free, having a membership opens even more doors to free resources, and other resources at a discount. Not only did the science teachers indulge in the myriad of three-dimensional resources, grade specific lessons, and journal articles, but they were also introduced to the Forum section. Here teachers can interact with science teachers from all disciplines, and all grade levels, but also pre-service through well-seasoned teachers in the field. There are many established and long running strands, including ones for rural and isolated science teachers, and if a teacher can't find a relevant strand for what they are seeking information/input on, they can start a new strand. The

Forums in and of themselves serve as a wealth of information, but most importantly, they provide a means for teachers across the nation to connect. Teachers continued to meet in grade and content groups throughout the school year using virtual techniques they practiced during the summer institute.

Research Methodology and Design

As described in the project overview, this project implemented two platforms of professional learning, hybrid and virtual. This study explored the experiences of teacher participants and their perceptions of the effectiveness of both types of connections, being that two sites were hybrid while another two sites were virtually connected during all presentations, break-out, and work sessions. Participants were engaged locally in district and building PLC conversations and worked across districts in grade level and content collaborations utilizing Zoom to host conversations between multiple sites.

Methodological Framework

Through the ethnographic lens, the case study design was the data collection methodology that framed this study. Ethnography has its roots in the field of anthropology, but many adaptations and interpretations have taken place throughout the course of the last century. Hammersly and Atkinson (2007) state, “the origins of the term [ethnography] lie in nineteenth-century Western anthropology, where an ethnography was a descriptive account of a community or culture, usually one located outside the West” (p.1). By the 1950s, ethnographies were being conducted in rural and urban settings and were exploring the cultures of unique groups of individuals as they lived through a phenomenon (Hammersly & Atkinson, 2007). This study used ethnographic methods to develop relationships between the researchers and the teacher participants to gain a deeper understanding of their experiences during the two-week summer institutes as well as school year coaching through the lens of face-to-face, hybrid, or virtual learning opportunities in rural and suburban locations.

Merriam (1998) suggests that case study design provides a rich account of social phenomena because it is “anchored in real life situations” (p. 41). Case study design has become useful for studying current educational processes, which aims to affect and improve future practices. Bhattacharya (2007) confirms this idea by noting, “Case studies are also targeted at information-rich sources for in-depth understanding and can also be used to inform policies or to uncover contributing reasons for cause-and-effect relationships” (p. 206). As the aim of this study is to explore the experiences of the rural teacher participants as they engage in virtual and hybrid professional learning, case study will be used because it “afford(s) researchers’ opportunities to explore or describe a phenomenon in context using a variety of data sources” (Baxter & Jack, 2008, p.544). For the purposes of this study, the ethnographic case study design allowed the researchers to explore each case, hybrid and virtual, in rural and suburban settings, on an individual basis using multiple data sources.

The ethnographic case study design allowed the researcher to explore the teacher participants’ ways of behaving, thinking, feeling, and understanding within the context of their school culture, especially of the rural districts as their cultural contexts each differ significantly from one another and their suburban counterparts. By bringing a team of teachers from each district together, either physically or virtually, through interviewing, observing, and surveying, the researchers were able to gain a better understanding of the cultural and social contexts of each district regarding professional learning. Baxter and Jack (2008) state, the “potential data sources may include, but are not limited to: documentation, archival records, interviews, physical artifacts, direct observations, and participant-observation” (p.554). Creswell (2013) reiterates this notion by suggesting, in case studies, the researcher explores cases or a case over time, through in-depth data collection procedures involving multiple sources of information such as observations, interviews, audiovisual material, documents, and reports. Aligning with these approaches, the researchers employed numerous forms of data sources, including observations, interviews, and document analysis.

Research Design

This is an ethnographic case study, designed to explore the experiences of teachers as they engage in face-to-face, hybrid, and virtual learning aimed at engaging rural and otherwise isolated teachers in high-quality professional learning from the comfort of their own school, without the additional travel and financial burdens. This study is situated within the scope of an ethnographic case study, including participant selection, research site, and researcher role. Creswell (2013) states, “the process of designing a qualitative study emerges during inquiry, but it generally follows the pattern of scientific research. It starts with broad assumptions central to qualitative inquiry, and an interpretive/theoretical lens and a topic of inquiry” (p. 65). Some of these characteristics have been laid out in the methodological framework; the remainder will be discussed in this section.

After setting the goals, project staff determined multiple districts throughout the state, located in rural, geographically isolated regions as well as districts close to the host universities as the main focus of the project goal was to engage rural teachers in professional learning opportunities alongside their suburban colleagues throughout the state. District administration e-mailed all of their K-8 teachers the opportunity to participate in a needs assessment survey prior to the start of the project. As part of this survey, teachers were asked if they were interested in participating in this grant opportunity. Eighty teachers responded as being interested. Schools as well as districts then assembled their ideal team of interested and available teachers to participate. We provided the following criteria to help them assemble and present their team to the project staff for selection: 2 to 4 teachers from elementary buildings and 2 to 4 teachers from respective feeder middle schools, for a total team of 6 to 8 teachers from each site as well as 1 to 2 building and district administrators.

As an incentive for teachers, they received a $1250 stipend for participation and leadership in the summer institute as well as follow-up continuing school-year coaching activities. Graduate credit in mathematics, science, or education was also available for all participants. Upon grant award and district team acceptance into the grant project, all participating teachers and administrators were asked to sign a statement of commitment. Districts either chose to remain fully virtual, hosting the professional learning in their own district buildings or to drive to a host university and attending some sessions face-to-face and others virtual for a hybrid experience. The following table includes a brief synopsis of each district team based on their hybrid or virtual attendance.

Table 1

District and Participant Descriptions

District Type	Attendance Type	Number of Buildings	Teacher Attendance	Administrator Attendance	Distance (in miles) from a host University
Suburban	Hybrid	3	4 elementary	1	40
Rural	Virtual	1	5 elementary 2 middle	1	220
Rural	Hybrid	2	6 elementary	1	25
Rural	Hybrid	4	17 elementary	3	25
Rural	Hybrid	5	6 elementary 4 middle	2	45
Suburban	Hybrid	1	2 elementary	1	75
Rural	Virtual	1	2 elementary	1	108
Suburban	Virtual	51	5 elementary	1	85
Rural	Hybrid	2	3 elementary	1	50

As noted above, interviews, observations, and qualitative survey data were collected from participants and analyzed based on their attendance type. The qualitative data was categorized for major themes that could be crucial in understanding the experiences of rural teachers, identifying perceptions of effectiveness of virtual/hybrid collaborations, and developing specific components of effective virtual professional learning based on these experiences and collaborations.

There were three goals as described in the project overview. Our ethnographic case study focused on goal three: to increase IHE and district collaborations with a focus on rural connection to suburban districts as well as IHEs. Our secondary aim of this goal was to develop a model of effective professional learning delivery that could sustain a statewide network of teachers, including rural and suburban districts, not bound by geographic regions.

Findings and Discussion

The data from this ethnographic case study will be shared through two lenses, first, the analysis of the teachers involved in the case study project, virtually and through hybrid interactions; and second, from the researcher's perspective on the design of virtual professional learning model to increase rural district access to resources and learning, which was a theme of the teacher findings. These two lenses are reciprocal in nature, one leading to the other and vice versa, as the model unfolded based on teacher needs collected throughout the study.

Prior to the summer institute, there were no inter-district communications among participants and little intra-district communication with peers teaching the same grade/subject.

The virtual sites were primarily rural/isolated teachers while the hybrid sites had a combination of rural and suburban teachers. Teachers who attended, whether virtually and hybrid, showed increased collaborations with their peers, both within and between districts, during the school year as well as demonstrated increased application of effective teaching practices based on responses from open format interviews and survey questions. Through the instructional coach observations and coaching activities along with survey and interview responses from teacher participants, the digging deep in content with the IHE faculty and mixed mode of engagement in content and pedagogy during the institute, it was evident that teachers were applying their increased content knowledge and beginning to embed the three dimensions into their teaching of science in their classrooms. Three major themes that were identified based on overwhelming recurrence in teacher and administrator open-response questions, categorized by type of experiences, virtual or hybrid.

The first major theme that was identified in the data by using axial coding, was the need for and appreciation of the explicitly designated collaboration time. As noted in the project overview, this time became progressively more teacher led and directed throughout the project. Teachers had set time to collaborate with their grade level, content specific counterparts between districts, rural and suburban, as well as time to collaborate with their building and district. There were also opportunities to cooperate and collaborate during the investigations and book studies. Table 2 shows teacher and administrator quotes that exemplify the need for collaboration within and between districts to enhance professional learning and sustained growth.

The second major theme that was extrapolated from the data was the lack of equitable access that many rural and isolated but also suburban teachers and administrators noted. Although their experiences were different, virtual or hybrid, it was evident that many participants from both groups had not previously had access to the resources and high-quality professional learning that they experienced throughout the project. In Table 3 below, teacher and administrator quotes are provided that focus on the project's ability to increase equitable access.

The final major theme detailed in the data included the teachers' increase in confidence in their STEM content knowledge and specific pedagogical content knowledge based on their experiences throughout the project, including summer institutes and school year coaching and subsequent professional learning. Table 4 showcases specific quotes from rural and suburban teachers, shedding light on the impact of their experiences related to their knowledge growth.

Table 2

Theme 1 Collaboration: Quotes from Virtual and Hybrid Teacher Participants

Theme 1: Need for Collaborations, within district and between districts	
Virtual Teacher Quotes	**Hybrid Teacher Quotes**
"We were very fortunate to have the opportunity to be a virtual site for this project, which allowed our teachers the convenience of staying home while participating in this PD." "Even though I was 100% virtual, I never felt left out, and it was great to be doing the investigations along with all the others. I loved using Padlet and seeing what my peers were doing and how they were thinking. The discussions during the book study were invigorating and enlightening and digging deep into the content was an amazing experience." "Out of a PK-12 building we were represented by the following grade levels: kindergarten, first, second, third, fifth, sixth, seventh/eighth, and high school, which allowed us to collaborate across the grade levels." "The network we built across the state has proven extremely helpful in maintaining access to my ever so helpful project peers." "I took full advantage of networking with my peers and having virtual discussions with my peers about their adoptions and the pros and cons they saw in the available options." "It was a good feeling to be able to put some of my colleagues in touch with other teachers across the state who taught the same thing so they could learn."	"The networking we did and the book study, investigations were fantastic springboards to help bring me up to speed. I am looking forward to staying in touch with my peers from the summer institute to support each other and steal their ideas." "Foremost was the chance for elementary teachers from two different buildings within the district to attend and bond together for two weeks. Collaboration like this is often thought of theoretically, but rarely does the time present itself to make it happen." "Building this state-wide network of peers during the project was such a comfort to have access to." "Building these connections over the past year has been great for me to stay in touch with others to get ideas or troubleshoot when I get stuck. I have no other teachers in my district that teach the same grade /content level, so this has been a blessing!" "Now, along with learning with my peers across the state from this project to support my teaching, I also can use the NSTA forums if my state peers are also at a loss to help me. It is hard being the only science teacher for your grade in the building, and it's almost impossible to find time to work with the other science teacher in our other elementary school."

Table 3

Theme 2 Equitable Access: Quotes from Virtual and Hybrid Teacher Participants

Theme 2: Equitable access to resources and learning	
Virtual Teacher Quotes	**Hybrid Teacher Quotes**
"Another benefit from the project were the resources and connections that we were able to make use of during the investigations and book study I learned about and feel ready to implement the 3-dimensions of NGSS in my classroom." "Having lacked access to adequate resources and PD opportunities for years, the gift of this project provided my growth in increasing my content and pedagogy by leaps and bounds." "Coming from a small rural district, access to such high-quality resources and little access to PD, or any content or pedagogical support was never available." "Never having had any pedagogy training in my district, I soaked up every ounce of information from the summer to help provide me confidence and knowledge. "Access to this kind of quality PD was never an option in my old district because it was so small and removed from any population center."	"Living and teaching out in the boondocks, I never thought I'd see an opportunity like this to have meaningful professional development." "The resources at NSTA are amazing. I can't believe I've been teaching for 5 years and never found these before. I will continue to use the NSTA content resources to find ready-made and tested lessons, and even more importantly do a better job of staying on top of current pedagogy best practices." "The biggest benefit from the project were the resources and connections to districts throughout the state." "I have been teaching for over 30 years but have never had this type of opportunity for professional development, nor any colleagues I could talk with about science content or best practices for teaching it."

Table 4

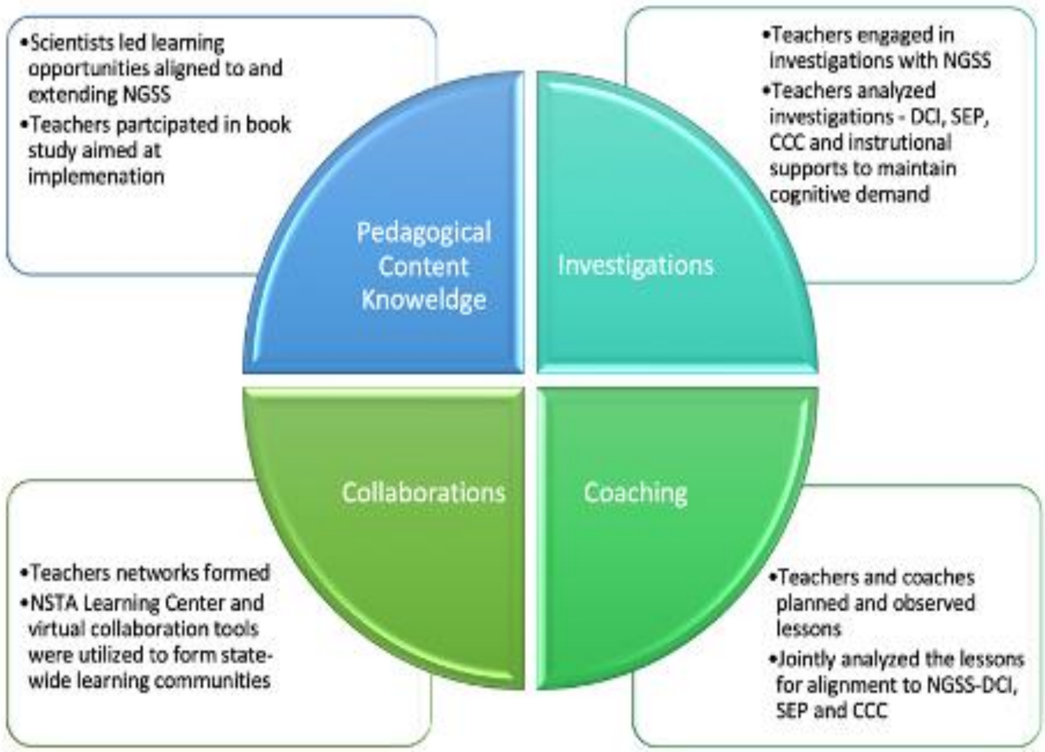
Theme 3 Increased Knowledge: Quotes from Virtual and Hybrid Teacher Participants

Theme 3: Increase in content and pedagogical content knowledge (coaching)	
Virtual Teacher Quotes	**Hybrid Teacher Quotes**
"We were able to have the tough conversations about aligning content across grade levels, common vocabulary, and goals that we would like to meet as a building in science." "My experience of the year-long coaching was of tremendous value and reinforced much of my learning during the summer." "Having been part of the project I now feel more confident in my instruction, especially when it comes to preparing engaging and rigorous content for students. In addition, being part of this project has pushed me to want to be part of more committees and experiences, all of which has contributed to keeping me up to date and knowledgeable of what is best practice for students." "When I had the opportunity to work with my coach and deliver very needed information and made it "fun and engaging" for my colleagues to learn, it was amazing how much more respect they had for what I had gained from the summer institute. After the PD, when I would be working with my instructional coach, if one of my peers found out they jumped in front of the camera and started asking questions of my coach."	"I have to admit the first few days I was scared and a little intimidated and wondered what I was doing here. I had never heard of the 3 dimensions and how they drive the teaching of science to all grades. By the second day I was relieved to know I was not alone in my ignorance." "I wish my college professors taught like the ones I had here. They never made me feel guilty about what I did not know, but just opened the doors to more content in a way that was very easy to grasp." "This project provided me with much needed exposure and learning of science and pedagogical content knowledge. I was a little concerned at the beginning of the grant that I was going to be the only one 'who knew so little' but it turned out that my peers from across the state were in the same situation as me! Gaining access to the resources and learning opportunities through this grant and knowledge of how to effectively use professional organizations like NSTA was a goldmine for me."

The identified growth of teachers as they engaged in high-quality virtual and hybrid professional learning, as they collaborated within a virtual STEM learning network, led to the development of the effective professional learning model with four integrated components. By collaborating with peers, both within and outside of their district during the pedagogical content knowledge learning investigations to reinforce STEM content and through teacher engagement in coaching activities during the training, the project was able to support individual teachers, as well as district and state level networks, to bring equity to rural and isolated teachers. Figure 5 (Thiele & Bogdon, 2020) showcases the effective science professional learning model that was derived from this project, based on teacher strengths, needs, and wants, as well as feedback on the success of the integration of each aspect, rather than training on each individual component in isolation.

Figure 5

Effective Science Professional Development Model



(Thiele & Bogdon, 2020)

The individual components of the model were identified during the planning phase and year one of the project, however, based on teacher and administrator input as well as the major themes that were identified in the participant responses, the integration of each component of the model, specifically the collaboration and networking that takes place throughout each aspect, is vital to the effectiveness.

From the perspective of the IHE content and pedagogy faculty, an improvement in IHE interdepartmental relationship was an additional finding of this project related to developing a statewide network. A STEM content faculty member who led content sessions stated, “Even though I teach mostly undergraduate science majors going on to med school or further degrees for research, I was humbled in participating in this project. I learned a lot from working with my pedagogy partner as I prepared for my deep content dive after the teachers finished their investigations. The pedagogy used for teachers to teach their students, can easily be applied into my teachings of science majors. I am excited to see the impact with my college students’ growth as I begin to work these practices into my teaching.” This level of collaboration is an additional perk of the integrated professional development model, to encompass content faculty in the development and implementation of professional learning, simultaneously increasing content knowledge of K-8 teachers and education faculty and increasing pedagogical knowledge of content faculty. This open sharing of skills, resources, and knowledge is a continued area, ripe for future research.

Future Considerations

The ethnographic case study provided evidence of increased collaborations, content knowledge, pedagogical content knowledge, and efficacy in using the knowledge and skills acquired during the project. The follow through of the instructional coaches with their assigned teachers, whether face-to-face or virtual, played a significant role in the success of teachers embedding their gains successfully in their daily routine. These rural and isolated teachers were thankful for the quality and opportunity to participate in such a rigorous project. The case study lens allowed the researchers and participants to simultaneously engage in and create an integrated professional development model to provide high-quality learning opportunities to teachers in rural and otherwise isolated districts. This project moved forward in identifying key components necessary for bringing equity in professional learning to our rural and isolated educators; however, further work is needed to identify steps to sustain this level of statewide professional network for years after the summation of a project and continue studying the long-term impacts of individual teacher and district participation. The development of a mechanism to assist with teacher transitions between districts as well as IHE access to districts would allow for more succinct collaborations to be maintained. Many rural district administrators were unsure how to reach out to IHEs to collaborate, so although both institutions were willing and had a desire to collaborate, the development of a sustained pathway to increase the frequency and ongoing nature of professional learning would increase efficiency and accessibility, specifically for rural and otherwise isolated districts.

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About the Authors

Julie Thiele, PhD, is an assistant professor at Wichita State University. She earned her PhD in Curriculum and Instruction with a focus in mathematics education from Kansas State University. She teaches elementary mathematics instructional strategies, internship, assessment, and mentoring courses and serves as the instructional coordinator in the Teacher Apprentice Program. She plays an active role in Kansas schools, leading professional development and conducting research in the areas of elementary in-service and pre-service STEM education with a focus on effective STEM teaching practices, specifically students' experiences with effective task implementation, questioning, assessment, and grading and reporting practices.

Ollie Bogdon, PhD, is an assistant professor at Missouri Western State University. She earned her PhD in Curriculum and Instruction focusing on science education partnered with a public affairs and administration concentration from University of Missouri Kansas City. As part of the teacher preparation program, she teaches the elementary science courses using many applied learning opportunities for her students in addition to media integration, introduction to education, and developmental psychology. Dr. Bogdon is also active in the graduate program guiding students through their capstone projects. She plays an active role in National Science Teaching Association's use and promotion of using their website as an electronic textbook, helping connect future science teachers to quality resources as they enter the classroom, and proposal reviewer for Association for Science Teacher Education. Current research areas include elementary in-service and pre-service STEM education with a focus on STEM readiness, teaching practices, and improving the critical "Triad" connections between standards, objectives, and assessments.

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Virtual Summer Institutes as a Method of Rural Science Teacher Development

Stephen L Thompson, Rachelle Curcio, Amber Adgerson, Kristin E. Harbour, Leigh Kale D'Amico, Hall S. West, George J. Roy, Melissa A. Baker, Jessie Guest, and **Catherine Compton-Lilly,** *University of South Carolina*

Key policy documents call for science teacher preparation programs to provide teacher candidates with approximations to authentic teaching experiences that occur in realistic contexts. Providing such opportunities for teacher candidates located in communities that are rural as well as geographically far from university settings is especially difficult. Stakeholders also point to the importance of positive coaching and mentoring relationships as key factors impacting the growth of teacher candidates. In this paper we discuss the positive potential of virtual science-related summer institutes as a vehicle to (a) provide authentic science teaching experiences for teacher candidates and (b) promote the development of positive coaching and mentoring relationships. We also share features of a summer science institute developed as a launch to our teacher residency preparation program that incorporated teacher candidates, school-based teacher educators, and university-based supervisors to maximize the potential positive impacts. Data included quantitative and qualitative post-institute survey data from teacher candidates, school-based teacher educators, and university-based supervisors. Findings revealed that residents' perception of their content knowledge development, pedagogical knowledge development, and overall effectiveness of the summer institute were high; additionally, school-based teacher educators and university-based supervisors indicated positive perceptions of the institute, noting their knowledge of coaching increased, helpful resources were provided, and institute structures promoted the development of positive coaching relationships. These results provide tentative evidence to support the continued use of virtual science summer institutes as a viable option for supporting both preservice and in-service teacher development.

***Keywords*: rural science teacher preparation, science camp, coaching**

A recent report from the American Association of Colleges for Teacher Preparation Clinical Practice Commission (American Association of Colleges for Teacher Education [AACTE], 2018) argued that the process of learning to teach requires sustained opportunities for teacher candidates to engage in authentic teaching experiences and contexts. Additionally, the report emphasized that clinical practice should be the framework through which all teacher preparation is designed and that teacher preparation systems be designed to allow teacher candidates to develop over time in collaboration with accomplished practitioners (AACTE, 2018). Similar recommendations are emerging from the science teacher preparation community. For example, key recommendations from a synthesis of research studies focused on new teachers of science emphasized that initial teacher preparation programs (a) need to be organized in a manner that encourages the cultivation of teaching practices over time and (b) be grounded in contexts that approximate future teaching environments (Luft et al., 2015).

While responding to these recommendations is difficult for science teacher preparation in general, creating such systems for rural science teacher preparation is especially challenging given rural teacher preparation's unique contextual factors (Huffling et al., 2017); additionally, much of the current research focuses on practicing or veteran rural teacher professional development rather than the preparation of new teachers (Annetta & Shymansky, 2006, 2008; Cicchinelli & Beesley, 2017). The distance associated with rural settings further exacerbate pressing issues associated with preservice science teacher development. Namely, that science methods instructors have few opportunities to observe teacher candidates' initial enactments of targeted instructional approaches or provide them feedback on actual lesson enactments (Lampert et al., 2013; Menon, 2020). Related research also emphasizes that teacher candidates who work in rural communities should learn teaching strategies appropriate for rural contexts (Burton et al., 2010; Institute of Education Sciences, 2013; Reagan et al., 2019) and that rural teacher preparation must be place-based and place-conscious (Greenwood, 2013).

To respond to these key recommendations from guiding teacher preparation policy documents (e.g., AACTE, 2018) and to mitigate many of the rural science teacher preparation obstacles highlighted in related research (e.g., Annetta & Shymansky, 2006, 2008; Cicchinelli & Beesley, 2017; Huffling et al., 2017), we created a Virtual Science Summer Institute (institute) as an initial component of an 18-month rural teacher residency program. The institute brought teacher candidates together with school-based teacher educators, university-based teacher educators, program faculty, and elementary students from the local community to take part in shared virtual teaching and learning experiences. The shared experiences occurred within authentic rural schooling contexts, provided teacher candidates with initial practice teaching opportunities, promoted the development of coaching and mentoring relationships, and allowed all stakeholders to develop a common lexicon and ways of thinking about teaching.

Literature Review: Rural Teacher Preparation

More than half of the school districts in the United States are classified as rural. However, the definition of rural varies widely in the literature, and there are many definitions for what constitutes a rural school district (Dunstan et al., 2021; National Center for Education Statistics [NCES], 2021; Reagan et al., 2019; Thier et al., 2021). NCES designates three types of rural communities: fringe, distant, and remote. Additionally, NCES defines fringe rural as "territory that is less than or equal to 5 miles from an urbanized area, as well as rural territory that is less than or equal to 2.5 miles from an urban cluster" (NCES, 2021, p.1). The Census Bureau delineates rural as "any population, housing, or territory NOT in an urban area" with urban areas being defined as an area with a population of more than 50,000 (United States Census Bureau, 2021, p. 1).

The wide variation in classifying rural schools and locales has affected the research on rural teacher preparation. Many scholars argue successful teacher preparation programs in rural areas must attend to the uniqueness of every rural locale (Greenwood, 2013; Huffling et al., 2017; Reagan et al., 2019). As a result, much of the literature focuses on the juxtaposition of the fixed and static locations of rural school communities and the ever-evolving cultural constructs that affect "the ways [they] talk about and enact 'rural'" (Reagan et al., 2019, p. 84). In other words, teacher education programs must emphasize the nuances of rural contexts while simultaneously focusing on the recruitment, preparation, support, and retention of teacher candidates (Huffling et al., 2017, Regan et al., 2019).

As a result of this ongoing dialogue, key recommendations for rural teacher preparation are advocated by multiple stakeholder groups. One key recommendation is that teacher candidates who will serve rural areas must be given opportunities in teacher education programs to learn explicit strategies for teaching in rural contexts (Burton & Johnson, 2010; Institute of Education Sciences, 2013; Reagan et al., 2019). For example, rural teacher candidates should be exposed to place-based theories that promote their learning about local communities and how to access local knowledge and expertise to support instruction (Eppley, 2011). Another key recommendation is that teacher candidates have field experiences and practicums in their preparation programs that lend themselves to the application of general education initiatives. More specifically, rural teacher education must be place-based and place-conscious (Greenwood, 2013). Even so, some teacher education programs that serve future teachers of rural communities focus more on rural teacher education than others. As an example, of nine teacher education programs serving teacher candidates in rural contexts, Barley (2009) found only four programs sought teacher candidates from actual rural communities. Additionally, two programs placed teacher candidates in rural communities, and only one program had coursework experiences in rural educational contexts. This lack of targeted programming and recruitment is relevant as programs with a focus on rural contexts are essential to the adequate preparation of teachers for rural communities. These omissions also highlight the importance of contextually based programs that take into consideration the geography, demographics, economies of each rural area and the implications on teacher candidates' social capital, identity, and culture (Huffing et al., 2017; Reagan et al., 2019).

Further, we argue that rural schools and the teacher education programs that serve rural communities, must be nuanced, and reflect the working theories of place and the cultural constraints within each rural community. While the research on rural teacher education in the United States has increased in the last decade and a half, there continues to be a need for more research on rural teacher education preparation in the midst of the technological shifts of the 21st century (Azano & Stewart, 2016; Cicchinelli & Beesley, 2017; Helge, 1985; Thier et al., 2021). As Azano and Stewart stated, "there is relatively little known about intentional efforts to prepare teachers specifically for rural classrooms" (2016, p. 108). The extant knowledge around rural teacher preparation is further exacerbated when considering the overlap of rural teacher education within the field of science. For instance, much of the current literature focuses on practicing or veteran rural teachers and their professional development within science teaching as opposed to teacher candidates (Annetta & Shymansky 2006; 2008; Cicchinelli & Beesley, 2017). To gain deeper insight, additional research in the areas of rural science teacher preparation is needed, especially in the areas of recruitment, retention, preparation, and ongoing support of teacher candidates (Burton & Johnson, 2010; Institute of Education Science, 2013).

Summer Camp Experiences for Rural Science Teacher Candidates

Several longitudinal studies highlight that teacher candidates have lower teaching self-efficacy in science and mathematics when compared to other content areas (Buss, 2010; Franks et al., 2016; Swars & Dooley, 2010). One possible intervention, summer camp experiences with a science focus, has been found to be useful in nurturing the science teaching self-efficacy of teacher candidates from various contexts (Franks et al., 2016). Franks et al. (2016) found that the self-efficacy of teacher candidates' science was enhanced through science summer camp experiences with primarily African American female students. A key outcome from the study was that 98.2% of the surveyed teacher candidates indicated the experiences were "the most useful aspect of the course in influencing their self-efficacy" in science (p. 70). Other study outcomes highlight that the opportunity to practice science within authentic contexts, like summer camps, can help teacher candidates confront their fears and misconceptions about science teaching methods and teaching students from diverse backgrounds (Franks et al., 2016; Swars & Dooley, 2010). Furthermore, experiences like these can also help teacher candidates understand the necessity of prior knowledge and its impact on students' conceptual change in science (Wallace et al., 2013).

Other studies support the notion that science related summer camp experiences can improve the academic outcomes and perceptions of participating youth (Edwards et al., 2001; Fields, 2009; Tichenor & Playchan, 2010). The positive influence of science-related summer camps is especially evident for students who reside in rural contexts. For example, research that examined the positive impacts of a virtual Science Technology Engineering and Mathematics (STEM) camp experience on the mathematics self-efficacy of rural middle-schoolers revealed that STEM camp experiences increased students' positive interactions with adults and peers, their math identity development, and their math self-efficacy (Lindt & Gupta, 2020). Despite their potential, much of the science summer camp literature focuses on contexts that are face-to-face and occur on university campuses or in K-12 schools. The contexts of these studies reveal the importance of school and university partnerships in the cultivation of summer science camp experiences in order to strengthen teacher candidates' science teaching self-efficacy while simultaneously providing programming and positive impacts for K-12 students (Petersen & Treagust, 2014).

This backdrop, and the changes to schooling contexts that occurred as a result of the COVID-19 pandemic, have coincided with an increase in virtual science-related camps (Louis & King, 2022; Scheina & CCDC C5ISR Center Public Affairs, 2020). Related research highlights that virtual STEM camps allow participants to engage in learning from multiple contexts such as their "bedrooms, kitchens, and cars" (Smith-Mutegi & Morton, 2021, p. 12). In addition to expanding our notions of classroom spaces, the shift to more virtual experiences also increased opportunities to participate in such experiences and created a wider audience of students who may be able to attend such camps (Mellieon-Williams et al., 2021). The shift to more virtual science camp experiences also highlighted important limitations of the approaches. For example, virtual experiences create the need for more physical support from adults who can assist participating students, which was seen as a drawback of the virtual science camp context (Fayed et al., 2021; Milbrath, 2021). The lack of broadband internet access in rural communities and technology gaps were also important limitations on the reach and impact of virtual science camps (Clemson Engineers for Developing Communities, 2020; Prensky, 2020).

The Virtual Science Summer Institute

With the literature in mind, our team sought to develop a Virtual Science Summer Institute that embodied tenets of clinically centered teacher preparation and science teacher preparation in rural communities. The institute, situated in an 18-month grant funded teacher residency model, served as a key programmatic component and was an initial program experience. The Carolina Transition to Teaching program supports the preparation of individuals who are transitioning into teaching from other careers. It is a masters level program in partnership with two local rural school districts, and all teacher residents reside within these districts. The institute sets the stage for the varied coursework and corresponding clinical practice experiences occurring throughout the entirety of the residency.

Specifically, our research team designed and facilitated a two-week institute as the launch to our teacher residency program. To support collaboration and learning among all stakeholders during the institute, a wide variety of participants were involved throughout the two-week experience. These participants included the following: teacher candidates (teacher residents), school-based teacher educators (coaching teachers), university-based teacher educators (supervisors), and program staff (i.e., university faculty, graduate assistants, and professional development providers). The institute immersed all participants in equity-centered, reform-based elementary science and mathematics teaching practices (e.g., National Council of Teachers of Mathematics [NCTM], 2014; Next Generation Science Standards Lead States, 2013). These immersive experiences were designed to establish a common base of knowledge about equity-centered science teaching and cultivate a collegial community of co-learners. Further, the institute focused on the following goals: (a) deepening residents' content and pedagogical content knowledge, (b) providing authentic opportunities for enacting content and pedagogy, (c) creating spaces for cultivating a reflective stance, and (d) developing coaching skills and dispositions.

The Virtual Science Summer Institute Overview

The institute occurred over the course of ten days in July from 8:30–3:30 daily and was held virtually using video conferencing software (i.e., Zoom). The daily agenda (see Table 1 for an example agenda) engaged participants in authentic experiences through the modeling and enactment of varied pedagogical strategies.

The institute was designed to support residents' growth in science, mathematics, and computer science content knowledge and pedagogy, with science content highlighted as the primary emphasis for daily instructional enactments. An overarching goal was to provide a space for teaching residents to learn common approaches to equitable science teaching and engage in supported initial science teaching experiences in a low-risk setting.

Table 1

Summer Institute Daily Schedule Samples

Week 1, Day Two		Week 2, Day Two	
Week One Sample Schedule		Week Two Sample Schedule	
8:30-9:00	Agenda and Opening Moves	8:30-8:45	Agenda and Opening Moves
9:00-10:00	Science Pedagogy	8:45-9:15	Rehearsals for Work with Students
10:00-10:20	Reflective Break	9:15-10:00	Teaching STEM
10:20-11:00	Unpack and Debrief Teaching and Pedagogy	10:00-10:30	Individual Reflection on Reaching and Break
11:00-12:00	Lunch	10:30-11:00	Whole Group Debrief and Reflection
12:00-1:00	Literacy	11:00-12:00	Lunch
1:00-1:15	Read Aloud	12:00-12:15	Read Aloud
1:15-2:00	Science Pedagogy	12:15-1:45	Culturally Sustaining STEM Pedagogy
2:00-2:15	Reflection Break	1:45-2:00	Reflection Break
2:15-3:15	Mathematics Pedagogy	2:00-3:15	Planning for Tomorrow's Teaching
3:15-3:30	Wrap Up and What's Next	3:15-3:30	Wrap Up and What's Next

Prior to the institute, all participants received a science kit, a box of common materials, that would be used during learning activities and lesson enactments. During week one, participants engaged as learners in model 5E Lessons (Bybee, 2014) focused on energy content aligned with state elementary science standards. During week two, students in grades 4-6 who were recruited from local partner schools joined the institute, and teacher residents engaged them in virtual science teaching experiences while coaching teams composed of coaching teachers, supervisors, and program staff observed and supported the teacher residents' initial science teaching enactments. Following each lesson enactment, teacher residents and coaching team members individually and collectively participated in reflective discussions focused on the teacher residents' science lesson enactments and goal setting for the next day's teaching enactments.

In the following narrative, we describe the critical design structures of our institute model. The first sections focus on structures designed to deepen participants' science and content knowledge and establish a coaching community. The next sections focus on structures designed to provide teacher residents with opportunities to apply and practice recently learned science pedagogy and for coaching teachers and supervisors to apply and practice recently learned coaching pedagogy.

Key Design Structures of Virtual STEM Summer Institute

Institute structures were designed to cultivate a collegial community of co-learners focused on an equity orientation to science teaching. At the onset of the institute, emphasis was placed on developing relationships across all stakeholders and establishing common norms and technological protocols. On day one, institute objectives were introduced to set the stage for a collegial experience situated in authentic practice. These objectives consisted of items such as: (a) observing, reflecting upon, and enacting science practices; (b) exploring strategies for establishing and maintaining culturally sustaining classroom environments; (c) creating collaborative opportunities to discuss institute-to-classroom connections; and (d) cultivating participants' inquiry and equity stance. These objectives were supported through varied institute structures and protocols that guided our day-to-day learning.

Of particular emphasis were the institute's shared science learning experiences that modeled targeted science pedagogical approaches while also promoting the development of a shared teaching lexicon and orientation. Additionally, throughout the institute participants engaged in activities designed to cultivate teacher residents' attitudes, skills, and dispositions for coaching while growing the coaching practices of both the coaching teachers and supervisors. The collective experiences provided the context for participant groups to focus on teacher residents learning how to teach science. The context also promoted the development of coaching practices and the establishment of a positive coaching community to effectively support the growth of teacher residents' teaching abilities. By establishing relationships and beginning this work in a safe, non-evaluative setting, the power structure inequities inherent in mentor/mentee relationships were reduced, a community of co-learners was formed, and a collective focus on effective science teaching was established.

Design Structure 1: Deepen Content and Pedagogical Content Knowledge

The first essential institute design structure was the intentional inclusion of experiences aimed at deepening content and pedagogical content knowledge for all participants. In addition to the focus on science content and pedagogy, the institute design strategically planned to strengthen coaching teachers' and supervisors' knowledge on the practice of coaching while also developing teacher residents' habits for being coached. The information below elaborates on these areas of this design structure.

Science Content and Pedagogy

At the beginning of the institute, all participants learned about 5E Learning Cycle approaches to science teaching (Bybee, 2014). Initially, as part of the coursework, teacher residents read an article that provided an overview of 5E Learning Cycle approaches. This article was also shared with coaching teachers, supervisors, and program staff. Then, participants took part in a model instructional sequence as learners that was led by a science methods instructor who was a member of the program staff. The initial lesson sequence focused on how to light a bulb using just a battery and wire. The modeled light bulb lesson was also the first science lesson the teacher residents would later enact with elementary students during week two of the institute. Following engagement in the model 5E lesson sequence, the collective group made explicit connections between the modeled instructional sequence and approaches they experienced and the targeted instructional approaches they read about. The modeled lessons were also designed to portray a coherent content storyline across the week one activities.

This technique, immersion in model 5E lessons followed by activities designed to make explicit connections to the instructional approaches, was repeated each day of the first week of the summer institute. This structure was supported by prior research, which highlighted that exposing elementary teacher candidates to the use of hands-on activities during science lessons (Watters & Ginn, 2000) and instruction about pedagogical techniques like the learning cycle (Settlage, 2000) has been shown to positively impact teacher candidates' science teaching self-efficacy.

Coaching Content and Pedagogy

A key component of the institute was the development of coaching teachers' and supervisors' coaching skills and the cultivation of teacher residents' dispositions for coaching. Through systematic professional learning and intentional coaching conversations, we sought to support the maturation of mentoring interactions and coaching team relationships – knowing that these items are interdependent of each other (Ambrosetti et al., 2014). During week one, these conversations were nurtured through dialogic conversations connected to reflecting on the modeled science methods instructional approaches. To facilitate these conversations, participants engaged in individual and group reflections using a program-developed observation protocol to guide discussions. Recognizing the importance of situating all participants as learners (Canipe & Gunckel, 2019; Turner & Blackburn, 2016), we intentionally created a Noticings and Wonderings observation protocol that allowed for all participants to actively contribute to reflective conversations. The goals for these conversations were twofold: (a) creating an authentic space for educative conversations focused on teaching and learning, and (b) providing opportunities for all participants to develop a common language and structure for reflection that could continue into the residency.

Another facet of establishing a coaching community was the inclusion of dedicated time to develop coaching teachers' and supervisors' coaching capacity. Additional professional learning occurred outside the institute agenda for coaching team members. These five one-hour sessions engaged coaching teachers and supervisors in content specifically focused on the role of a coach, co-teaching as a catalyst for mentoring interactions, and the strategic use of our Noticing and Wondering coaching observation protocol. Objectives for these sessions centered on (a) establishing a cadre of coaches – a community of school-based and university-based teacher educators working together to enhance teaching and learning in rural school settings, and (b) developing a repertoire of technical and interpersonal coaching skills that would, in turn, inform resident learning. To support the facilitation of our coaching community, sessions were structured to encourage dialogue on the coaching process, with the final session occurring during week two; thus, allowing coaches to reflect on the application of their skills. By focusing on developing an educative community that authentically situated all participants as learners, the institute promoted the forming of mentoring and coaching partnerships and supported the establishment of teacher observation and related conferencing routines, norms, and practices.

Design Structure 2: Authentic Application of Content and Pedagogy

The next institute design structure focuses on the authentic application of learned content and pedagogy. Responding to AACTE's Clinical Practice Commission Report (2018), this design structure provided intentional pedagogical experiences grounded in contexts that approximated future science teaching environments (Luft et al., 2015). Moreover, these experiences guided teacher residents through intentional reflection on their teaching and on student learning. In addition to the authentic application of science content and pedagogy, various opportunities were provided to engage in authentic coaching. Coaching teachers and supervisors were provided space to practice coaching, and teacher residents were immersed in coaching conversations – setting the stage for a culture of coaching. The information below elaborates on the authentic application design structure across science and coaching pedagogy.

Application of Science Pedagogy

At the end of week one, teaching teams (2-3 teacher residents) were formed and paired with a coaching team (composed of coaching teachers, supervisors, and program staff). Then each teaching team, with support from their coaching team, planned and rehearsed the first virtual 5E lesson sequence they would enact with small groups of elementary students (n = 4-5) the following Monday. The first lesson focused on how to light a bulb with just a wire and battery. Teaching teams were given instructional materials (presentation slides) that outlined the lesson and teacher residents were encouraged to follow the same initial sequence they experienced as learners. Following the enactment of the lesson, the teaching and coaching teams individually, and then collectively, reflected on the enacted lesson using the same process and protocol from week one. These conversations enabled participants to debrief about the enacted lesson, engage in coaching conversations, and establish individual goals for each teacher resident to focus on during the next lesson enactment that would occur the following day.

Each day during week two continued this pattern. Teaching and coaching teams engaged in afternoon planning and rehearsing of science lessons that would be enacted by teaching teams the following morning with elementary students. Teaching teams were provided with daily instructional materials (presentation slides) that outlined the lesson for the following day. However, fewer details were provided each subsequent day so that coaching teams could promote teacher residents' gradual assumption of responsibility for lesson planning, with support.

The scaffolded and supportive approach focused on a pressing need for the teaching residents, learning how to teach science (Luft, et al., 2015). It was also supported by related research findings that highlight that teaching science to elementary students can positively impact elementary teacher candidates' science teachers' self-efficacy (Cantrell et al., 2003) and that science teaching experiences and opportunities to practice reform-based science teaching approaches were the primary factors to positively impact teacher candidates' science teaching self-efficacy (Swars & Dooley, 2010). These approaches also provided opportunities for teacher candidates to collaboratively plan, rehearse, and enact lessons that are informed by the methods course instructor, coaching teacher, and supervisor feedback. In this way our approaches mitigated key weaknesses identified in science teacher preparation, that science methods instructors rarely observe teacher candidates' initial enactments of targeted instructional approaches or provide them with feedback on actual lesson enactments (Lampert et al., 2013). Further, practice teaching science lessons accompanied by post-lesson reflective sessions with goal setting and monitoring for future science lessons have been shown to be instrumental in changing teachers' understanding of inquiry teaching and their beliefs about how students learn science best (Lotter et al., 2017).

Application of Coaching Pedagogy

Throughout the entirety of the institute, participants were engaged in authentic experiences that supported their enactment of coaching skills and cultivation of dispositions for coaching. As noted previously, week one of the institute was a space to deepen participants' knowledge of coaching, develop common capacity, and nurture coherent coaching language, thus, setting the stage for the application of this knowledge during week two. The structure of week two provided varied opportunities for coaching teachers and supervisors to apply and practice coaching skills, and this structure gave teacher residents opportunities to be coached.

The institute's week two design created repeated opportunities for daily coaching: a 20-minute pre-teaching rehearsal, in-action coaching during science instruction, post-teaching reflective coaching conversations, and a 45-minute planning session to close the day. These processes were used repeatedly as instructional strategies to nurture teacher residents' reflective stance and develop habits of mind to guide their future teaching. Additionally, during week two teaching enactments, coaching team members used the Noticings and Wonderings protocol during lesson observation to gather data, inform coaching conversations, set teacher resident goals, and plan for the next day's teaching. This structure, and consistent use of the observation protocol, provided coaching teachers and supervisors opportunities to practice coaching in a parallel manner to the residents' practice teaching. The intentional inclusion of authentic opportunities to enact coaching knowledge and pedagogy aligns with the assertions that mentoring and coaching in teacher preparation should be viewed as a professional practice (He, 2010; Schwille, 2008), a practice that is strategically developed and supported over time.

Findings

To explore teacher residents' and coaches' (i.e., coaching teachers and supervisors) perceptions on the design and implementation of our institute, we collected post-institute survey data. Survey questions were both quantitative (Likert-scaled) and qualitative (open-response) in nature and were given to all teacher residents, coaching teachers, and supervisors approximately one week after the completion of the two-week institute. As our overarching goals were to create a collegial community of co-learners and develop science and coaching knowledge, two surveys were created to collect data from our two distinct participant groups (i.e., teacher residents and school- and university-based coaches). The teacher resident and coaching teacher and supervisor surveys are provided in Appendix A and B, respectively. Below we highlight initial findings across these groups as well as offer recommendations from lessons learned.

Teacher Resident Data Overview

Nine teacher residents participated in the post-institute survey, including 5-point Likert-scaled items and open response items. In the following section, we provide evidence around teacher residents' perceptions of content knowledge development, pedagogical knowledge development, and overall effectiveness of the summer institute.

Teacher residents reported the summer institute increased their knowledge of targeted STEM, Computer Science, and Literacy content, with particularly high outcomes noted in the teacher residents' perceptions of their gains in STEM and Computer Science content knowledge, with means of 5.0 and 4.78 respectively (scale ranged from strongly disagree response as a 1 to strongly agree response as a 5; n = 9). Additionally, teacher residents' responses to open-ended writing prompts also supported the notion that the Summer Institute resulted in content knowledge gains. For example, when asked, "*What did you gain from your experience at the Institute?",* the majority of the Teacher Residents (n=7) referenced content knowledge gains.

Survey results also revealed that participation in the summer institute increased the residents' perceptions of their pedagogical knowledge across targeted content areas, with especially high mean scores noted in STEM and equity-centered pedagogical approaches (n = 9, with means of 4.71 and 4.92, respectively). Additionally, regarding general pedagogy, residents indicated a 4.57 (n = 9) response, meaning agree to strongly agree around the question of "*Please rate how prepared you feel to implement the strategies learned at the Institute in the classroom.*" Open-ended response also highlighted that teacher residents found the virtual teaching experiences with elementary-aged students helped them feel more comfortable interacting with and teaching elementary-aged students. For instance, one resident wrote, "*I really loved the hands-on feel of being able to interact with the students."*

The increased teaching preparedness reported in survey responses was supported by open responses as well. A key program component referenced by many teacher residents were the practice teaching experiences. Here a resident wrote about the authenticity of work with students at the onset of the program: "*It was a great introduction of what is to come along. . . . We also got to practice what we learned."* Teacher residents further shared that the virtual practice teaching experiences gave them confidence in the effectiveness of the targeted instructional approaches and confidence in their own abilities to enact them. For example, when responding to the prompt "*What did you gain from your experience at the Institute?"*, responses such as "*I gained confidence in myself. As to how I plan to carry out my tasks as an instructor*" and "*Confidence in my ability to teach*" were typical.

Finally, when asked to rate the effectiveness of the institute and the related virtual learning format, teacher residents assessed both highly. Residents were asked to rate the overall effectiveness of the institute on a scale of 1-5, with 1 being not effective and 5 being very effective. The resultant mean was 5.0, indicating very effective across all residents (n = 9). Additionally, residents indicated a 4.85 rating (n = 9) for the effectiveness of the virtual format of the institute.

Coaching Teacher and Supervisor Data Overview

Nine coaching teachers (n = 7) and supervisors (n = 2) participated in the post-institute survey, including 4-point Likert-scaled items and open-response items. When asked to identify the usefulness of the professional learning sessions explicitly connected to coaching, the majority (n = 8) indicated the sessions were *very useful* (score of 4) and one individual noted the sessions were *somewhat useful* (score of 3), resulting in a mean score of 3.89. All coaching teachers and supervisors reported *somewhat increased* or *substantially increased* awareness of resources and supports related to their roles (n = 9; *M* = 3.56). Additionally, two coaching teachers reported being *not at all prepared* to serve in their role prior to the coaching sessions; however, following our coaching sessions, all coaching teachers reported being *somewhat prepared* (score of 3) or *very prepared* (score of 4) to serve in their role (n = 7, *M* = 3.71).

When asked how participating in the summer institute prepared them for their role as coaching teachers and supervisors, multiple coaching teachers and supervisors mentioned that the institute assisted them in getting to know the residents, and one reported a greater understanding of the residents' roles and how to help them succeed in the classroom. Specifically, one coaching teacher noted that the institute "*gave me insights into [the residents'] personality and working closely with a new teacher*" and it enabled them to develop relationships to "*correct misconceptions while guiding and mentoring lessons*." Similarly, another coaching teacher appreciated the ability to "*practice over the summer and receive tips before beginning my role*."

Coaching teachers also shared they liked receiving helpful resources, and they appreciated the opportunity to interact with and get to know residents and supervisors when asked "*What did you like most about the coaching sessions?*" Additionally, the supervisors appreciated the collaborative nature of the sessions and found the ability to interact and work with the coaching teachers prior to the school year as beneficial. All coaching teachers and supervisors indicated appreciation of "*being involved in the development process*" for the Noticing and Wondering observation protocol with one coaching teacher stating they felt *"heard"* and another feeling like "*a valuable part of the team*."

Discussion and Recommendations

Outcomes from the institute revealed that teacher residents, coaching teachers, and supervisors placed high value on the opportunities to practice their newly learned respective strategies and approaches. Both participant groups indicated the opportunities to enact learned content and pedagogy resulted in enhanced confidence and feelings of preparedness. The collective findings give us assurance that similar experiences may assist in mitigating some of the most pressing science teacher preparation issues while also benefiting the collective efficacy of teacher candidates, coaching teachers, and supervisors in other teacher education contexts.

Within our institute, each teacher resident engaged in approximations of reform-based science teaching and collaborated in real time with experienced science educators (Luft et al., 2015). The teaching feedback residents received was immediate and grounded in a shared authentic context and set of experiences. Our teacher residents indicated the structure provided a safe environment where they could practice teaching and gain science teaching confidence. These features highlight how the approaches diminish constraints associated with other more independent practice-based science teacher preparation approaches such as creating opportunities for each teacher candidate to practice instructional strategies with students and ensuring teacher educators can observe and provide feedback on teaching enactments that occur in authentic settings.

Recognizing that embedded experiences similar to the institute create educative environments that promote learning for all stakeholders, we recommend that when planning future experiences design teams focus on the cultivation of authentic settings for learning that situate all participants as learners engaged in shared sense-making (AACTE, 2018; Canipe & Gunckel, 2019). One key institute component that contributed to providing space for shared sense-making was the use of the *Noticing and Wondering* protocol. Similar to Wood and Turner's (2015) findings centered on the importance of professional learning tasks that encourage shared discussion, our work extends these findings through the incorporation of a shared protocol to guide conversations. The *Noticing and Wondering* protocol aligned with our context and programmatic objectives of cultivating an inquiry stance (Cochran-Smith & Lytle, 2009); thus, we encourage others to design or identify discussion protocols coherent with their contexts.

In addition to developing participants' content and pedagogical content knowledge, the shared experiences at the institute promoted the development of a positive coaching community. Coaching teachers valued "in the moment" opportunities to practice coaching as well as the promotion of positive working relationships between teacher candidates, coaching teachers, university supervisors, and program staff. The ability to enact coaching practices laid the foundation for coaching throughout the residency, and the intentional cultivation of a cadre of coaches joined together by a common mission established a sense of collegiality among coaching team members. Similarly, teacher residents appreciated the coaching supports received during the institute as well as the collegial relationships they developed with coaching teachers, supervisors, and program staff. With this in mind, we recommend providing opportunities for partners in teacher education to strategically connect prior to the onset of the final clinical experience, and if possible, to incorporate authentic teaching enactments within these experiences. As Thompson and Emmer (2019) noted in their study centered on professional learning held prior to the final internship, intentionally designed shared learning experiences similar to our institute provide critical spaces for relationship development. Extending upon this research, we designed a clinically centered experience that provided all participants space for growth. The inclusion of this design feature fostered clinical partnerships that not only influenced our coaching community but also became the vehicle for future collaborative science clinical experiences to become operational (AACTE, 2018).

Connected to these findings, we wonder how professional learning of this nature might be used more widely to provide context-rich, clinically centered professional learning to science educators in rural contexts - not just teacher candidates. Currently, local and international literature note the use of virtual professional learning communities to connect rural teachers in learning networks (Rolandson & Ross-Hekkel, 2022) and discuss the availability of asynchronous virtual learning experiences to support rural teacher development (Herbert et al., 2016); however, connections to authentic application of content and pedagogy appear to be absent from these models. Thus, we posit that professional learning experiences similar to the institute may become viable spaces for providing access to high-quality, clinically centered professional learning coherent with the needs and structures found in rural contexts.

While the experiences from our virtual summer institute revealed potential for expanding the reach of clinically centered teacher preparation into rural communities, we recognize our model has some limitations and there are lessons to be learned. First, we note that our institute was supported through grant funding and that constrained resources may restrict the extent to which these collaborations can flourish in non-funded spaces. Additionally, since our institute was connected to a grant, structures were in place at the university to support the significant time commitment needed to implement the institute's design, planning, implementation, and evaluation. For preparation programs interested in designing similar institute experiences with current resources, we recommend considering existing structures that may lend themselves to creating clinically centered shared learning opportunities situated in authentic science teaching.

Other limitations of this work are also important to consider. While feedback from participants was favorable, we acknowledge that our approach has only been implemented by one research team in one university setting. Therefore, we seek to engage in additional iterations of research within new rural partnership contexts centered on the institute's influence on teaching, coaching, and learning. Likewise, we encourage others who engage in institutes of this nature to conduct research. Our field would benefit from more robust research that explores varied institute design and implementation models and their impact on not only science instruction but more importantly science learning.

Conclusion

Authentic teaching experiences in collaboration with accomplished practitioners is an essential part of teacher preparation programs (AACTE, 2018); moreover, teacher preparation programs must attend to the unique contexts in which they serve (AACTE, 2018), such as within rural communities (Huffling et al., 2017; Regan et al., 2019). However, continued research is needed within rural teacher preparation (Azano & Stewart, 2016; Cicchinelli & Beesley, 2017; Helge, 1985; Thier et al., 2021), and even more so in the area of rural science teacher preparation (Burton & Johnson, 2010; Institute of Education Science, 2013). To address the extant literature around science teacher preparation in rural communities and expand on the positive findings related to science camps and teacher candidates (Franks et al., 2016; Seung et al., 2019), we developed a two-week virtual summer institute as a launch to our residency-based preparation program. Within the institute, we sought to create a community of co-learners among teacher candidates, school- and university-based teacher educators, and program staff. Specifically, we engaged in immersive experiences designed to establish a common base of knowledge about equity-centered science teaching and effective coaching practices. Findings indicated that the residents' perception of their content knowledge development, pedagogical knowledge development, and overall effectiveness of the summer institute was high; additionally, coaching teachers and supervisors indicated positive perceptions of the institute, noting their knowledge of coaching increased, helpful resources were provided, and space for relationship building with the residents was established. Through these findings and lessons learned, all groups of participants placed a high value on the embedded and authentic opportunities to enact their newly learned strategies and expressed increased confidence and feelings of preparedness. By building our institute around tenets of effective teacher preparation in general, and within rural communities specifically, results provide promising, albeit tentative, evidence to support the continued use of virtual science summer camps as a viable option for supporting both preservice and in-service teacher development.

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About the Authors

Stephen Thompson, PhD, is a professor of Elementary Science Education at the University of South Carolina. Dr. Thompson's primary research interests center on improving elementary and middle level science education, especially in high-need communities, through teacher development focused on the use of reform-based teaching strategies. He has been a leader in his local professional development school network and views such partnerships as instrumental in addressing some of the most pressing issues in K-12 science education.

Rachelle Curcio, PhD, is an assistant professor of Teacher Education at the University of North Florida. Her research and interests are grounded in an inquiry stance and focus on aspects of clinically-centered teacher preparation with an emphasis on preparing teachers for racially, ethnically, and linguistically diverse 21st-century classroom contexts. Specifically, Rachelle's research is centered on the supervision and coaching that occurs in clinical spaces as well as the cultivation of teachers' critical curriculum literacy skills connected to their role as curriculum makers.

Amber Adgerson, is a native South Carolinian, scholar, and educator activist who brings over a decade of practical, public-school experience to the field of academia. She is currently pursuing a PhD in Teaching and Learning at the University of South Carolina. Guided by her experiences as a former classroom teacher, her research focuses on STEM and teacher education.

Kristin E. Harbour, PhD, is an associate professor of Elementary Education in the Department of Instruction and Teacher Education, College of Education at the University of South Carolina. Her scholarship includes support systems for advancing teachers' ambitious and inclusive mathematics teaching practices and teacher preparation with a focus on authentic experiences to navigate the complexities of the teaching and learning of mathematics. She serves as the professional development school liaison for a local elementary school and focuses on supports to recruit, prepare, and retain teachers through clinically centered partnerships.

Leigh Kale D'Amico, EdD, is a research associate professor in the Research, Evaluation, and Measurement Center in the College of Education at the University of South Carolina. Her research focuses on early childhood education, PK-12 curriculum and instruction, teacher preparation, professional development, and student success.

Hall S. West, PhD, is a research associate at the Research, Evaluation, and Measurement Center in the College of Education at the University of South Carolina where she serves as an evaluator for various educational programs and efforts across South Carolina.

George J. Roy, PhD, is a professor of Middle Level Education at the University of South Carolina. He was a public-school mathematics teacher where he earned a National Board of Professional Teaching Standards certification in Early Adolescence Mathematics. Currently, Dr. Roy teaches in the Department of Instruction and Teacher Education. His current research interests include examining uses of technology in mathematics classrooms, pre-service teachers' development of mathematical knowledge for teaching, and university-school district partnerships.

Melissa A. Baker, PhD, is a professional track assistant professor at the University of South Carolina. She is committed to school–university partnerships (SUP) and serves as chair of the American Education Research Association Profession Development Schools Research Special Interest Group (AERA PDSR SIG), secretary of the National Association of Professional Development Schools, past-president and board member of PDS SERVE, and co-creator of the Southeastern PDS Research Consortium. Dr. Baker's research centers on the intersections between clinically-centered teacher preparation, recruitment, induction, and retention within PDS and SUP partnerships, primarily in rural settings.

Jessie Guest, PhD, is a clinical assistant professor at the University of South Carolina where she received her PhD in Counselor Education and Supervision. Dr. Guest is the coordinator of the Graduate Certificate in Play Therapy and a Licensed Clinical Mental Health Counselor Supervisor and Registered Play Therapist Supervisor. Jessie's research interests and publications consist of social emotional learning, mindfulness, play therapy, countertransference, and trauma.

Catherine Compton-Lilly, EdD, is the John C. Hungerpiller Professor at the University of South Carolina. Dr. Compton-Lilly teaches courses in literacy studies and works with professional development schools in at the University of South Carolina. She has a passion for helping teachers to support children in learning to read and write. Her interests include examining how time operates as a contextual factor in children's lives as they progress through school and construct their identities as students and readers. She is the author and editor of several books and has published widely in educational journals.

Appendix A

Please take a few minutes to complete this brief survey regarding your experience at the Transition to Teaching Summer Institute. Your responses will be anonymous and will be used to help improve future learning experiences for our residents.

* 1. Please rate the overall effectiveness of the Transition to Teaching Summer Institute on a scale of 1-5, with 1 being *not effective* and 5 being *very effective*.

1 (Not effective)	2	3	4	5 (Very effective)
○	○	○	○	○

* 2. To what extent did your content knowledge increase in the following areas as a result of participation in the Institute?

	1 (No increase)	2	3	4	5 (Significant increase)
STEM	○	○	○	○	○
Computer Science	○	○	○	○	○
Literacy	○	○	○	○	○

* 3. To what extent did your pedagogical knowledge (teaching strategies and techniques) increase in the following areas as a result of participation in the Institute?

	1 (No increase)	2	3	4	5 (Significant increase)
Equity	○	○	○	○	○
Inquiry	○	○	○	○	○
Cultural sensitivity	○	○	○	○	○
Creation and maintenance of responsive classroom environments	○	○	○	○	○
STEM	○	○	○	○	○
Computer Science	○	○	○	○	○
Literacy	○	○	○	○	○

* 4. Please rate how prepared you feel to implement the strategies learned at the Institute in the classroom.

1 (Not at all)	2	3	4	5 (Very prepared)
○	○	○	○	○

* 5. To what extent do you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The virtual learning format was effective.	○	○	○	○	○
The virtual learning format was engaging.	○	○	○	○	○
The virtual learning format was organized.	○	○	○	○	○
The virtual learning format was accessible.	○	○	○	○	○
The virtual learning format supported a sense of community among the residents, mentor teachers, and instructors.	○	○	○	○	○

6. What did you like about the Summer Institute?

7. What did you gain from your experience at the Institute?

8. What do you wish would have been included in the Institute? What activities and supports do you think should be included?

9. What aspects would you improve about the Institute?

10. How might we improve the virtual learning aspect of coursework?

11. What else would you like to share with us about your experience at the Summer Institute?

* 12. What age range do you fall into?

- Below 30
- 30-39
- 40-49
- 50-59
- 60 or above

* 13. How much experience do you have working with students in a school setting including this past school year (2019-2020)?

- No experience
- Less than 1 year
- 1 to 2 years
- 3 to 4 years
- 5 to 6 years
- 7 to 8 years
- 9 to 10 years
- More than 10 years

Appendix B

Thank you for serving as a coaching teacher in the Carolina Transition to Teaching Program. Your work is contributing to the preparation of future teachers in South Carolina.

Please take a few minutes to share your thoughts and feedback related to the Coaching Teacher Professional Development. Your name will not be requested on the survey, and your responses are anonymous.

1. How would you describe the Coaching Teacher Professional Development? 0

- ◯ Very useful
- ◯ Somewhat useful
- ◯ Not very useful
- ◯ Not at all useful

2. How much did participating in the Coaching Teacher Professional Development increase your awareness of resources and supports related to your role as a coaching teacher? 0

- ◯ Substantially increased
- ◯ Somewhat increased
- ◯ Slightly increased
- ◯ Did not increase

3. Please indicate your level of preparedness to serve as a coaching teacher before the Coaching Teacher PD and after the Coaching Teacher PD. 0

	Very prepared	Somewhat prepared	Not so prepared	Not at all prepared
Before Coaching Teacher PD	◯	◯	◯	◯
After Coaching Teacher PD	◯	◯	◯	◯

4. What did you like **most** about the Coaching Teacher PD? 0

5. What did you like **least** about the Coaching Teacher PD? 0

6. Would you recommend that coaching teachers attend training (like the Coaching Teacher PD) prior to mentoring student teachers or residents? 0

- Definitely
- Probably
- Probably Not
- Definitely Not

7. What could be improved about the Coaching Teacher PD for future coaching teachers? 0

8. How beneficial do you think the residency model will be in the following areas?

UofSC residency model includes coaching teacher and resident teacher working together during an entire school year while the resident is completing coursework toward a master's degree. 0

	Very beneficial	Somewhat beneficial	Not very beneficial	Not at all beneficial
Preparing Effective Teachers				
Increasing Retention of Teachers				
Promoting Teacher Leadership				
Increasing Student Achievement				

9. Did you attend the Summer Institute with the residents? 0

- Yes
- No

10. How beneficial was the Summer Institute in preparing the residents for the upcoming school year? 🗨 0

- ◯ Very beneficial
- ◯ Somewhat beneficial
- ◯ Not very beneficial
- ◯ Not at all beneficial

11. What suggestions do you have to improve the Summer Institute to prepare the residents for the upcoming school year? 🗨 0

12. How did participating in the Summer Institute prepare you for your role as a coaching teacher? 🗨 0

13. What are your current thoughts about serving as a coaching teacher during the 2020-2021 school year? 🗨 0

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Rural Teacher Attitudes and Engagement with Computing and Technology

Melissa P. Mendenhall, Colby Tofel-Grehl, and **David F. Feldon,** *Utah State University*

The purpose of this sequential Case Study-Mixed Methods research is to explore rural teacher attitudes toward, approaches to, and engagement with making and computational thinking during STEM professional development and co-teaching learning experiences. Specifically, we examine the professional learning needs of two rural, middle school teachers as they engage technology. Using the lens of cultural historical activity theory, this paper examines the ways in which teacher attitude about computing shifted throughout professional learning and instructional practice. Findings show three broad themes that emerge surrounding teacher attitudes, approaches, and engagement with technology: Anxiety, Independent Learner, and Integration. Additionally, findings suggest that teacher attitude toward technology can be moderated through the means of a more knowledgeable other who scaffolds teacher learning and integration of technology.

***Keywords*: computational thinking, middle school, mixed-methods research, professional development, teacher attitudes**

Current STEM education efforts are neither achieving equitable outcomes for all students, nor meeting the demands of the workforce (Bureau of Labor Statistics, 2014; NSF, 2013; PCAST, 2016). According to data, early educational experiences influence students' options for future careers by informing their sense of compatibility of their personal identities with STEM possibilities and academic preparation (DeWitt & Archer, 2015). For example, research from a longitudinal study (Tai et al., 2006) found that half of 8^{th} grade students who identified with a STEM career ultimately earned a baccalaureate degree related to STEM while only one-third of students who did not identify with a STEM career graduated with a STEM related degree. This suggests a need to integrate STEM learning experiences into instruction that provides foundational knowledge, promotes interest and awareness of STEM career opportunities, and prepares students to be informed citizens.

Within STEM, computing is increasingly required across disciplines. This is seen in new fields such as chemometrics and computational biology. Accordingly, students need the support of educators in scaffolding both their and their students computing understanding to prepare for STEM career success in the future (Weintrop et al., 2015). Teachers also need the ability to develop student STEM identities during instruction (Margolis et al., 2015). Unfortunately, current computing experiences in education tend to not include authentic and meaningful integration that is relevant to STEM problems (Barron et al., 2003; Delgado et al., 2015; Pitman & Gaines, 2015). Additionally, the pedagogical content knowledge that allows teachers to engage students effectively, authentically, and meaningfully in integrated computing and STEM projects is lacking, resulting in limited development of the knowledge and skills necessary to build student pathways toward STEM careers that include computing (Hofstein & Lunetta, 2004; Kafai & Burke, 2014).

One way to support students in engaging computing is maker education, which allows youth to engage in computing and engineering while learning core disciplinary STEM classroom content using nontraditional materials such as electronic textiles (e-textiles) to build circuits that integrate with microprocessors (Peppler & Glosson, 2013; Tofel-Grehl et al., 2018). Through e-textiles, students incorporate programmable electronic components into fabric crafts as a way to understand circuitry instead of the traditional wires and breadboards. E-textiles utilizes materials such as conductive fiber and Velcro; light, sound, and pressure sensors; and LED actuators along with traditional fabric craft materials. Through e-textiles, students can work on authentic projects that are culturally relevant to them while developing physics knowledge and coding skills, which students desperately need to better prepare for future STEM careers.

However, implementing computational thinking tasks into instruction requires that teachers understand programming. It requires a familiarity with technology, computer science, circuitry, and the technological pedagogical content knowledge needed to support students in making sense of these components (Tofel-Grehl et al., 2022). However, teachers often report that they do not have the skills to engage students in STEM learning with computing (Searle & Tofel-Grehl, 2019). Thus, additional professional development is needed. This sentiment is also noted by Gaytan and McEwan (2010) who report that one of the main goals of professional development in the 21st century is to build the capacity of teachers to "integrate instructional technology into teaching practices effectively" (p. 77). By building in professional development time for teachers to learn, reflect, and apply knowledge and skills related to computing and technology into instruction, teachers are supported to make the shifts necessary to change instruction to more authentic and meaningful STEM learning (Avci et al., 2020).

Unfortunately for rural teachers, access to this professional learning can be an issue. Educators within rural communities typically receive less professional development than their counterparts in urban spaces for a wide range of reasons, including limited staffing, funding, and proximity to sources of professional development (Howley & Howley, 2004; Oliver, 2007; Rude & Brewer, 2003; Weitzenkamp et al., 2003). This is especially true for professional learning regarding integration of technology (Alexander et al., 2014; Jones-Kavalier & Flannigan, 2008; Nasah et al., 2010), which can affect the ability of teachers to implement STEM instruction.

Furthermore, rural teachers may also be less qualified and prepared from the start of their careers. Rural teachers tend to be hired from within their communities over generations, as it is hard to recruit and retain more qualified teachers from outside the community (Cowen et al., 2012). In fact, the more rural the school, the less hiring practices can be utilized to support improved classroom instruction of STEM due to the lack of candidates in the prospective hiring pool (Barrett et al., 2015). This exacerbates, among other issues, a lack of understanding in integrating STEM and particularly technology into instruction (Alexander et al., 2014; Jones-Kavalier & Flannigan, 2008; Nasah et al., 2010).

An additional piece to consider in shifting classroom instruction is teacher attitudes and beliefs. Research suggests that knowing teacher attitudes is critical for professional development, because teachers tend to teach what they believe is important (Bullough & Baughman, 1997; Pajares, 1992). On the other hand, Guskey (2002) suggests teacher attitudes toward a desired shift to instruction do not occur until teachers have tried a new instructional strategy and found evidence of positive student outcomes as a result. Either way, it appears that knowing educator attitudes toward using a practice "is critical for understanding teachers' thought processes, classroom practices, [and] change" (Smith, 2002, p. 42). In this case, the practice is the ability to engage with technology in general and in the classroom.

Therefore, to improve STEM learning and career outcomes for students by increasing STEM instruction through engagement with technology and computing, this research focuses on exploring rural teacher attitudes, approaches, and engagement with technology. Gaining understanding of these teachers' attitudes toward, approaches to, and engagement with technology, can inform the need for professional development in rural communities and the design of the professional learning experiences in order to scaffold rural educators' abilities to include technology, such as e-textiles, in STEM education for their community of students. Accordingly, we pose two research questions:

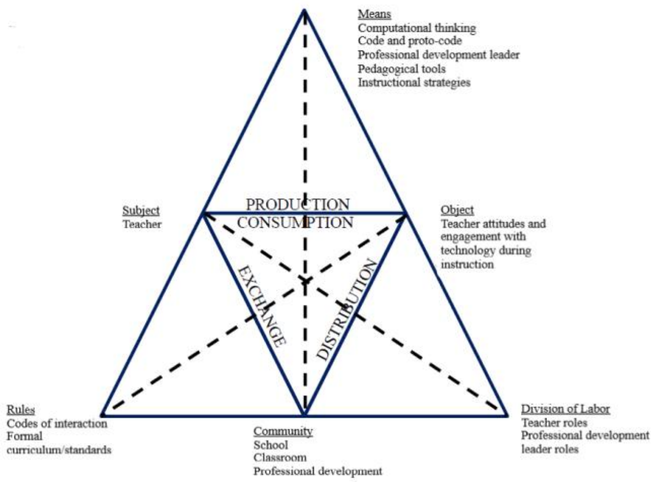
1. What attitudes do rural teachers express toward technology and computing both in general and within their classrooms?
2. How do rural teachers approach and engage with technology both during professional development and during classroom instruction?

Theoretical Framing

Through the lens of cultural historical activity theory (CHAT; Engeström, 1999), this research conceptualizes professional development in schools as activity systems within which teachers (subjects) and professional development (means) jointly endeavor to enrich teachers' understanding of technology implementation in instruction, particularly teachers' attitudes toward, approaches to, and engagement with technology (object). Integral to this activity structure are the tools and signs used to mediate the relation of subject to object. In this case these tools include teacher understanding of STEM instruction and pedagogical skills and strategies used in STEM instruction. These tools and signs are at times developed from within the activity system. However, members of the participating community, in this case the classroom, can also draw them in from other activities or prior experience (Greeno & Engeström, 2014). Thus, teachers may draw on their experiences with technology, computing skills, and other pedagogical constructs as tools to increase their abilities to implement technology into instruction. Further, as members of the activity system community, teachers are likely to adopt and transform these tools and representations over time (Schwarz & Hershkowitz, 2001) as ways to support future students in their pursuit of learning outcomes. We anticipate these practices will manifest as "crystalized operations" (Leont'ev, 1978) that are transparent to all community members (i.e., not objects of consciousness), because they facilitate modes of common meaning given the longevity of the existing computing curriculum. As such, teachers are likely to be more reflective about encounters with these conceptual tools as constructions of meaning new to their instructional design (Koschmann et al., 1998). Figure 1 illustrates the relationships that will frame the study.

Figure 1

Activity Framework for Professional Development



Note: (Adapted Roth & Lee, 2007)

Methods

To explore rural teacher attitudes toward, approaches to, and engagement with technology, this study uses a sequential CS-MM design that nests quantitative data analysis into qualitative analyses of researcher field notes and memos to surface themes in the data responsive to the research questions. These themes are then explored through reflective interviews with the participating teachers to enhance understanding of teacher attitudes, approaches, and engagement with technology.

Context and Participants

This article is part of a larger mixed methods study exploring rural teacher practices and professional learning around computing. The focus of the project was to build the capacity of teachers to include computational thinking in core STEM disciplinary classes.

Rural Hawaii (the Big Island) was selected as the site of this research because of the lack of teacher professional development on the island. The town in which the schools reside is located halfway between the two cities on the island. The workforce in this county is highly dependent upon local agriculture with a migrant population of 78%. Of the folks in the town, the native Hawaiian population is 31% with a 70% free/reduced lunch rate.

The two rural teachers participating in this study were selected for their prior teaching experience and availability during the COVID-19 pandemic. Amy (pseudonym) is a non-native, White woman who moved to the island eight years ago. She is National Board Certified, teaches middle school, and has been teaching for over 15 years. Jill (pseudonym) is a White woman who has lived on the island her whole life. She, too, taught middle school during the time of this project and has been teaching for over 15 years.

As an initial entrée to professional development, the teachers engaged in co-development of the curricular materials and projects over the course of three months. This co-design and development process involved teachers articulating topics and areas of interest that they wanted to improve within their classrooms and define spaces in which they could engage technology within their classes. Throughout this process the PD team engaged the teachers in iterative design and improvement of the projects in order to provide the teachers with scaffolded professional learning around each of the selected topics while simultaneously providing students greater opportunities to engage in computing within their schooling environment. After that three-month period of professional learning and co-development had concluded, teachers engaged in one-on-one professional learning over several days with the lead PD provider. A total of ten hours was spent together during this process. Teachers were trained on the specific projects they would be leading and constructing. The professional development model to be deployed in the classroom was also discussed and modified as needed. Due to the COVID-19 pandemic, several tweaks to professional development were needed. For example, while one of the test schools afforded the PD experience of multiple classes in which to model the instruction for the participating teacher, due to COVID restrictions, the second school was not able to structure their program this way. However, they were able to provide extended class periods which meant that the PD provider was able to model the lesson and then turn over instruction to the participating teacher. In both approaches, the PD provider prepared the teacher, modeled for the teacher, and then acted as co-teacher support person as they embarked on their first instructional experiences with the projects and computing. Both teachers received immediate and post-class feedback in order to support their instruction.

Design

This study utilizes a Case Study-Mixed Methods (CS-MM; Guetterman & Fetters, 2018) design, which draws upon the strengths of a case study design for exploration of a phenomenon in an authentic situation and affords the collection of data from multiple sources (Guetterman & Fetters, 2018). Additionally, it offers the ability to compare experiences with the phenomenon across multiple cases when more than one case is involved. Qualitative data collected from the cases were analyzed inductively and then quantitized (Saldaña, 2021) to gain “insight into whether the quantitative and qualitative results confirm, contradict, or relate” (Guetterman & Fetters, p. 914) to each other by elucidating patterns in the data through multiple lenses. This method supports deeper understanding of the phenomenon under exploration, which in turn helps the researchers to develop more focused questions to ask participants to confirm or disconfirm emergent themes.

Data Collection

Field notes were collected during professional development and the summer classes. Field notes were then open coded for this study from the perspective of the study’s research questions. As themes emerged through open coding, the researchers recorded these instances and other trends in the data through creating memos. Interviews were conducted following the mixed methods analysis of the field notes to confirm or disconfirm initial themes.

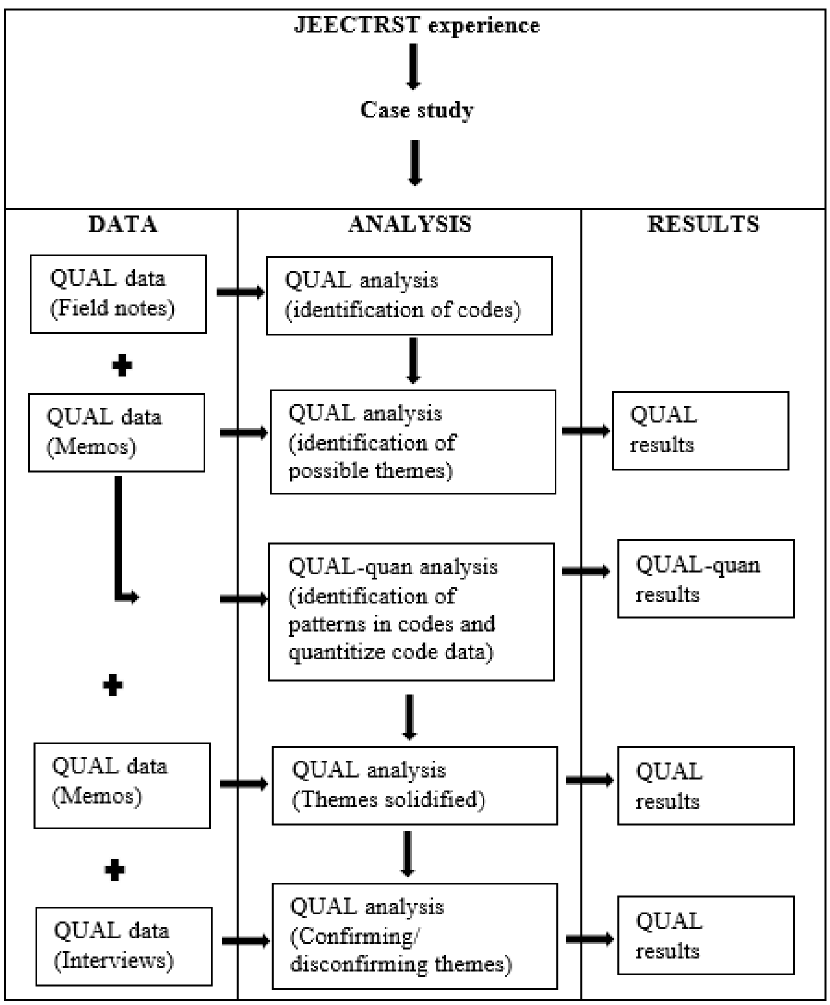
Analysis

Field notes were initially coded using open coding (Saldaña, 2021). Throughout the process, the researchers wrote memos to explain coding choices and processes as well as to document any emerging themes (see Figure 2). Frequency analyses were then applied to the qualitative codes to facilitate triangulation of inferences drawn (Greene et al., 1989).

Qualitative and quantitative data were compared to refine and solidify emerging themes. For the qualitative mixed methods analysis, the first-round codes were listed sequentially in the order they emerged from the text. The list of codes was then color coded to visually display any trends or patterns in the data. Additionally, codes were clustered into like categories. Finally, transcripts of interviews were searched for confirming or disconfirming evidence related to the themes (Saldaña, 2021). Also, transcripts were explored for any new themes that emerged in relation to teacher attitudes and approaches toward technology

Figure 2

Visual Display of Research Design: CS-MM



Findings

The initial codes from the field notes were first clustered into like codes where possible (e.g., Learning from mistakes=Learns quickly) and then listed sequentially to identify patterns as seen in Figure 3. The patterns were then described as possible themes. For example, patterns of multiple codes in Amy's personal learning and co-teaching data pointed out an overwhelming concern or anxiousness during learning and instruction (e.g., Teaching insecurities, Anxious focus on planning, Anxiety over learning about technology). This theme is Anxiety.

Figure 3

Visual Display of Coding Patterns/Clustering Data Segment

	Personal learning	Co-teaching
Amy	Teaching insecurities Teaching insecurities Teaching insecurities Teaching insecurities Anxious focus on planning Anxious focus on planning Anxious focus on planning Anxious focus on planning Anxious focus on planning Anxious focus on planning Anxious focus on planning Excited about technology Excited about technology Integrating other content with technology Excited about technology Excited about technology Excited about technology Anxious focus on planning Anxious focus on planning Anxious focus on planning	Anxiety over learning about technology Technology is lower priority Technology is lower priority Technology is lower priority Technology is lower priority Technology is lower priority Technology is lower priority Disconnect between teacher and students Anxiety over learning about technology Disconnect between teacher and students Teacher insecurities Teacher insecurities Technology is lower priority Lack of desire to plan, prepare, teach Anxiety over learning about technology Disconnect between teacher and students Teacher insecurities Anxious focus on planning Anxious focus on planning Anxious focus on planning
Janice	Learns quickly Learns quickly Learning from mistakes=Learns quickly New to educator "Frills free and efficient" Structure supports learning "Frills free and efficient" Independent learner Independent learner Independent learner Independent learner Structure supports learning Lack of attention to detail Learns quickly Lack of attention to detail Technology is valuable and useful for learning Lack of attention to detail	Focused on learning to teach technology Independent teacher with own ideas Discovery learning=Teaching philosophy Explicit teaching=Teaching philosophy Explicit teaching=Teaching philosophy Ignore student technology learning issues Discovery learning=Teaching philosophy Lack of attention to detail Explicit teaching=Teaching philosophy Positive attitude toward learning technology Independent teacher with own ideas Independent learner Independent teacher with own ideas Technology is lower priority "Productive struggle" Disconnect between teacher and students Disconnect between teacher and students

A second theme surfaced from the data for Jill in the codes Learns quickly, Independent learner, Independent teacher with own ideas, "Frills free and efficient", and Lack of attention to detail all converged around the notion of autonomy in learning. This theme is Independent Learning.

Additionally, when analyzing the code patterns for both teachers, the code Technology is lower priority seemed to precede the code Disconnect between teacher and students. This theme is labeled: Disengagement. Hence, the following initial themes emerged in relation to the teachers' attitudes toward, approaches to, and engagement with computing:

1. **Anxiety**: Overwhelming concern toward learning and instruction. For example, in the initial codes, Amy demonstrated patterns of teaching insecurities, anxious focus on planning, and anxiety over learning about technology and was anxious about approaching and engaging with technology during both the personal learning and co-teaching components of the professional development.
2. **Independent Learning**: Desire for autonomy in learning. For example, in the initial codes for Jill, ideas of independence to choose the speed of learning (e.g., "Frills free and efficient") as well as independence to choose what to focus on during learning and instruction (e.g., Lack of attention to detail, Independent teacher with own ideas) emerged.
3. **Disengagement**: Disengagement with technology preceded disengagement with students. Specifically, the codes Technology is lower priority and Disconnect between teacher and students appear in tandem with each other in both Amy's and Jill's coding patterns.

Frequency analysis of the quantitized initial qualitative codes is depicted in Tables 1-2 for Amy and Tables 3-4 for Jill.

Table 1

Frequencies of Top Four Codes for Professional Learning: Amy

Professional Learning (n=45)		
Coding category	**Frequency**	**Percent**
Anxious focus on planning	26	57.8
Teaching insecurities	7	15.6
Integrate with technology into learning	6	13.3
Excited about technology	5	11.1

Table 2

Frequencies of Top Four Codes for Co-Teaching: Amy

Co-Teaching (n=42)		
Coding category	**Frequency**	**Percent**
Technology is lower priority	9	21.4
Disconnect between teacher and students	5	11.9
Teacher insecurities	5	11.9
Lack of desire to plan, prepare, teach	4	9.5

Table 3

Frequencies of Top 4 Codes for Professional Learning: Jill

Professional Learning (n=41)		
Coding category	**Frequency**	**Percent**
Independent learner	6	14.6
Learns quickly	6	14.6
Positive attitude toward learning about technology	5	12.2
"Frills free and efficient"	4	9.8
Lack of attention to detail	4	9.8

Note: Five categories are listed due to a tie in fourth place. Quotation marks indicate an in Vivo code.

Table 4

Frequencies of Top Four Codes for Co-Teaching: Jill

Co-teaching (n=53)		
Coding category	**Frequency**	**Percent**
Technology is lower priority	18	34.0
Disconnect between teacher and students	7	13.2
Teaching strategies for student learning	5	9.4
Independent teacher with own ideas	4	7.6

When comparing the quantitative data findings to the qualitative themes for convergence of evidence, similarities were found. First, the **Anxiety** theme was heavily noted in Table 1 (i.e., most frequent codes from professional learning: Amy) and was one of the top four codes listed in Table 2 (i.e., Most frequent codes from co-teaching: Amy). Additionally, codes seen in Tables 3-4 depicted the **Independent Learner** theme with four of the top five codes in Table 3 (i.e., Most frequent codes from professional learning for Jill) and one of the codes in Table 4 (i.e., Most frequent codes from co-teaching for Jill) reflecting this idea.

Additionally, **Disengagement,** was observed in Tables 2 and 4 code frequencies, which reflect most frequent co-teaching codes for both teachers. It makes sense that this theme would be found in co-teaching codes only and not professional learning codes because it involves teachers working with students. However, it is interesting that this theme appeared in the data findings for both teachers.

Also of note, when comparing the quantitative findings to the themes from that qualitative data analysis, one top frequency coding category found in Table 1, Integrate with technology into learning, did not come to the researchers' attention during the initial theming process. This particular quantitative finding became important during the interviews and analysis that followed.

Interview Data Analysis

After completing the mixed methods analysis and generation of interview questions, follow up interviews were conducted with both participants to dive deeper into the initial themes. Findings from the data analysis of the interviews with both teachers consistently confirmed both the **Anxiety** and **Independent Learner** themes. For example, during the interview, Amy responded: "I've always had a hard time conceptualizing coding…the idea that I had to learn this and then, and then like possibly have to answer questions in like help [of students]" and "You're presented with new things and asked to do new tasks that you don't know how to do, you're anxious about it" all confirm that the **Anxiety** theme was present. Also, the **Independent Learner** theme was observed in the transcripts of Jill's interview through responses such as: "I have low exposure [to technology], but I'm kind of comfortable fiddling. I mean, I feel bad if I do something wrong, but like I'm not scared of it" and "I like to have time working independently through something…just because I don't like the pressure of like going too slow, going too fast, that kind of stuff."

Of note, through interview the teachers did not perceive their own disengagement but rather focused on the **value of the professional development dynamics**. This was evidenced in the ways that the teachers focused and talked about them with the professional development and professional development provider. From the perspective of the professional development provider, the goal was to develop a sense of collaboration and co-learning with the participating teachers in order to manage their feelings of trepidation to engaging with computing.

The process of working with the teachers began months before the summer schools were held. During this time the PD provider met bimonthly with the participating teachers to develop projects and curricular materials that met their specific classroom goals. For example, one of the participating teacher's classroom instruction focused on biology and the turtles of Hawaii. To that end, she provided regular feedback and brainstorming efforts to the PD team to develop projects and materials that dove deeply into her content of interest for the summer program. The other teacher was interested in the developing student agency and interest around Hawaii's sacred spaces so she worked with the PD provider to develop the Advocacy Apps project, a student lead app program that taught students about land stewardship and advocacy for proper behavior on the island. In this way, early on the professional development providers ensured that teachers were codesigning and learning about the projects and curriculum they would teach in the summer. This made the transition into formal professional learning smoother and provided a more equal footing for both sides to learn from.

The teachers appeared to have the same joint learning expectations as the professional development provider. They expected the professional development provider to be a support for them and their instruction as both teacher and provider worked through instructional shifts together. For example, during Jill's interview she explained

> Well, I think [that] certainly having the person demoing [the coding] being an expert teacher is what you want, right, so I think you really need a vet, who's doing the demos because I've done that, right, where you've seen a teacher and you're like, oh boy. So having an expert or master teacher [is] beneficial.

Here we see Jill simultaneously recognizing the expertise of the professional development provider but also not feeling different or lesser because of it. In fact, she associates it with times that she has been the expert instructor and provided those models to other teachers. She goes on further to say "I had to rely a little on [the professional development provider] because we hadn't gotten [to that part of the lesson with the prior group]," which indicates her comfort with leaning on the PD provider as a resource. From Amy's perspective she noted:

> I want to learn things that I can use in my class…and that are addressing my needs. I know that sounds kind of selfish, but things that are addressing my needs and things that I want to do, like for instance, the app. That was something that I really wanted to learn how to do. [The professional development provider] was like super flexible in sort of just let[ting] me do that, let me learn that…I sort of got my inspiration from [her].

Because of the relationship between the teachers and the provider that allowed for the joint construction of learning, the dynamics of the professional development supported teachers to shift instruction. These dynamics were important moderators of teacher interest and engagement with computing and technology. By feeling a part of the design process and believing the PD provider was there to provide them service rather than direct them, these relationships created opportunities for adoption and risk taking for the teachers.

Another important piece of this relationship may be that both teachers and provider viewed the relationship as positive. This was noted in the interview with Jill as she explained "the most comfortable I felt were times when I had…viewed [the professional development provider] run into…issues with students when she was modeling [the instruction]. Then, I was better versed at how to solve this [issue]." Also, Amy added as a follow up to interview questions the comment "every time I asked [the professional development provider] for something, she [said] yes." It appears that both of these teachers felt positive about the relationship because they felt comfortable learning from the provider and asking her for help.

By modeling productive struggle with computing and technology, the professional development provided gave teachers a better sense of how to scaffold such challenges within their own instruction. These scaffolds again acted as moderators for the teacher attitudes towards engaging technology and computing within their own teaching. Both teachers focused on the value of the relational dynamics of the professional development process. The aspects of joint creation of learning and positivity that spurred an ease of working together emerge as critical components of professional development.

Therefore, when considering the attitudes expressed by teachers both in general and within their classrooms, it appears that the relationship between the teacher (subject) and their attitudes toward computing with technology (object) were moderated by a specific means (professional development). Amy's initial attitude toward computing and technology was one of anxiety. However, during the interview, she appeared to relax and be more optimistic when discussing time spent with the professional development provider. Specifically, she expressed that the professional development provider was able to answer all her questions and provide her with the tools she needed to integrate computing and technology into her curriculum.

For Jill, her expression of being an independent learner also appeared to moderate when discussing the idea of implementing computing into her classroom instruction. She expressed the desire to have help learning how to integrate computing into her curriculum. This, too, could be accomplished by means of a professional development provider. Jill's independence was observed most robustly in the projects during which she engaged most carefully within the professional development. In other words, her independence was mediated by the professional development and her attention to it.

In both cases, the professional development provider served as means to moderate teacher attitudes by supporting teachers as they developed in their learning of computing and technology. The dynamics of this moderation resembled action as a more knowledgeable peer that supports others in developing through what Vygotsky (1978) termed the zone of proximal development (Salomon & Perkins, 1998; Wertsch, 1992).

For both teachers, their ultimate desire with learning about computing and technology was to enhance and deepen their content knowledge. Thus, they approached and engaged with technology from the perspective of using it to effectively teach content. Integration was a critical reason for their engagement with technology, which prompted the creation of a new theme: **Integration**. This replaced the **Disengagement** theme because it better explained teachers' reasons for viewing technology as a lower priority. Interestingly, this also explains one of the most frequent codes for Amy's professional development (See Table 1) in the quantitative analysis, Integrate with technology into learning. In hindsight, this code was an indicator of a larger theme:

3. **Integration**: Computing deepens or enhances learning in the content. Specifically, computing is an instructional strategy that provides a way for teachers to support effective and efficient student understanding of content knowledge.

Overall, all three themes suggest that getting teachers to engage with the tools (computing and technology) required or will require a more knowledgeable other (Vygotsky, 1978). This allowed Amy to feel confident and secure in integrating computing and technology into instruction and allowed Jill to see how to integrate computing and technology more fully into her instruction in ways that deepen and enhance the content. Therefore, it appears the most important moderating factor in allowing teachers to consume and produce computing and technology during professional learning experiences was the professional development provider. This person provides the means for helping teachers feel confident, capable, and able to implement the new strategy into instruction.

Discussion

This article showcases the beliefs and experiences of rural teachers seeking to engage in teaching with technology. Of all the means experienced by the teachers in this study, it was their relationships with the professional development experience and the professional development provider that moderated their beliefs about technology. We see shifts from anxious and avoidant behaviors to accepting and engaging behaviors. When asked, the teachers felt that this shift was possible for them because of the support of the professional development provider. This speaks to the value and importance of slow and tailored professional learning for rural teachers. Given the paucity of professional development offered to rural teachers, it may be that these relationships have stronger moderating influences on teacher attitude and belief.

Our research suggests that providing professional development for rural teachers within their home contexts coupled with a collaborative approach to engagement fosters teacher engagement and interest in teaching computing and engaging technology in their classes. Professional development provides a unique opportunity for rural teachers to serve as both peer and more knowledgeable other within their own classrooms as they develop their own learning. While the beliefs and attitudes experienced by rural teachers are often shifting, finding means that can facilitate shifts in belief can better support technology engagement and adoption within classrooms.

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Appendix

A1. Guiding questions and Key Construct for the Reflective Memo:

Guiding questions:

1. How has our work centered the problem of developing powerful learning experiences for youth (in and out of school) that ignite interest in STEM and computing and develop career connections?
2. What kinds of local partnerships can make that more of a possibility? (Penuel et al., 2020).

The **key constructs** involved in these memos are

3. Bridging: facilitating connections with initiatives and other operating parts of the partner organizations.
4. Buffering: creating protective spaces for those working in the project that keeps possible contradictory guidance, policy, or leadership at bay.
5. Shared tools involve development of tools used for asynchronous, ongoing collaboration, including capturing decisions and feedback for improvement. (Yurkofsky et al., 2020)
6. Informal support: Ongoing work that helps partners as they implement youth learning experiences that are not captured in other representations of the partnership. Ex. Helping with a technological issue.

About the Authors

Melissa P. Mendenhall, MA, is currently pursuing a PhD in Education, Curriculum and Instruction, Concentration in Science Education from Utah State University after completing a Master of Arts, Teacher Education, Integrated STEM emphasis from Brigham Young University. Her main research interest includes finding ways for all students to access effective STEM instruction. As the Elementary Science and STEM Specialist for the Utah State Board of Education, Melissa hopes to build the capacity of educators to scaffold disciplinary literacy in students, thereby providing them with the knowledge and skills to participate in STEM discourse and prepare for STEM career pathways if they so choose.

Colby Tofel-Grehl, PhD, is an associate professor of science education in the School of Teacher Education and Leadership at Utah State University. Her research focuses on finding ways to engage technology within core content STEM classrooms to create more equitable learning opportunities and supports for youth STEM identity development. Her research has appeared in *The Physics Teacher, Journal of Educational Research*, and *Journal of Science Education and Technology*. In 2020, she was honored with the early career Science Teacher Educator of the Year award from the Association for Science Teacher Education.

David Feldon, PhD, is a professor of instructional technology and learning sciences at Utah State University. His scholarship engages two foci: (1) identification of mechanisms of learning and motivation in postsecondary STEM education and (2) their interactions with structural barriers that hinder equitable career trajectories. His research attempts to build bridges from a deep understanding of motivation and cognition to broader cultural and structural influences that shape divergent pathways to expertise and modes of professional success.

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STEMulating Interest with a Rural Place-Conscious Curriculum

Elaine Westbrook, *Montana State University Billings*

This study was designed to investigate rural cultural and social influences that are uniquely different from other areas that could inform or shape the development of students' science, technology, engineering, and math (STEM) interest. Previous research focusing on place-conscious designs in rural locations has not explored how to increase student interest in STEM. This study investigated the effects of three informal instructional methods (hands-on, role model, and culminating projects) in a place-conscious curriculum on STEM interest. Participants included youth in third through fifth grades who attended two local schools in one community. Results indicated STEM interest increased through collaborative work, new knowledge, and action research. This study will help fill the gap in rural-based empirical studies of STEM interest development, informal education, and youth ages 8–12.

***Keywords*: STEM interest, rural, place-conscious, informal programming, hands-on, role model, culminating project**

Over 50 years ago, educational policymakers in the United States increased their attention and funding toward strengthening education in the science, technology, engineering, and math (STEM) disciplines. At that time, the focus was on developing a better understanding of "changing societal contexts such as communicable diseases and manufacturing demands" (National Academies of Sciences, 2019, p. 23). Despite years of effort, students' STEM knowledge growth has not reached desired outcomes. This critical deficiency needs to be addressed, and rural communities could hold the answers. Rural communities may provide a more diverse viewpoint on the current global developments of STEM demands and offer a more varied approach to solutions and applications. In 2010, the President's Council of Advisors on Science and Technology (PCAST) developed the *Prepare and Inspire* report indicating a significant gap in interest levels and achievement for underrepresented groups in STEM disciplines.

Interest has been defined by Harackiewicz et al. (2016) in their manuscript describing educational interest interventions as:

> a powerful motivational process that energizes learning, guides academic and career trajectories, and is essential to academic success. Interest is both a psychological state of attention and affect toward a particular object or topic, and an enduring predisposition to reengage over time (p .220).

Researchers' empirical and experimental studies have furthered the knowledge of interest and how it plays a crucial role in strengthening the learning process (Krapp, 1999). Conversely, researchers have also found that a lack of interest can result in apathy, unsuccessfulness, disengagement, inattentiveness, unskillfulness, and stagnation (Hidi, 1990; Renninger & Hidi, 2020). However, STEM interest can be increased through informal contexts and place-conscious curriculum design (Dierking et al., 2003; Eshach, 2006). This combination could decrease the equity and diversity gap for STEM pursuits by targeting a different audience (Vaziri et al., 2020).

STEM is an integrated approach to teaching more than science, technology, engineering, and math together but rather "the teaching and learning of the content and practices of disciplinary knowledge which include science and /or mathematics through the integration practices of engineering and engineering design of relevant technologies" (Bryan et al., 2015, p. 23–24). One place where STEM interest could be developed is in informal contexts where the learners operate outside of objectives and timelines and focus on seeking knowledge in everyday situations. Unlike formal educational structures, research suggests that *informal* program designs stimulate participant interest due to the absence of pressures from any external assessment (Dierking et al., 2003; Rogoff et al., 2016). Because informal learning has been shown to increase student interest and performance in science, developing informal curricula that align with science standards taught in formal classroom settings could help support students' STEM outcomes.

Some informally structured programs fail to gather data from their rural participants for designing programming contexts, principally for STEM. The resulting informal programs can be inaccessible (Showalter et al. 2019), and their contexts are irrelevant to rural participants' STEM interests (Mohr-Schroeder et al., 2014). Advantageous curricula would have a place-conscious focus to address a rural participant's interest. Gruenewald (2003b) defines place-conscious curricula as the inclusion of location factors with sociological effects. Place-conscious curricula provide opportunities to bridge local STEM issues and institutional knowledge while nurturing local youth's interest (Buxton, 2010; Johnson et al., 2009). Rural children bring a rich diversity to their understanding of STEM from their local rural knowledge. Previous research suggests that students in rural areas possess distinct funds of knowledge from their households and social networks (Moll et al., 1992).

Prior research tying place-conscious pedagogy and informal practices utilized various approaches, including examining subject context with hands-on experiments to explore the community's natural history; exploring cultural journalism through local videos and news stories from their community; and developing public service announcements to be locally distributed as action research (Buxton, 2010). However, little is known about which instructional methods utilized in a place-conscious informal STEM program supports the development of STEM interests. As previously reported, rural locations may lack programs that consider the rural narrative about STEM and the distinctiveness of their particular STEM background (Girl Scout Research Institute, 2012). Thus, this study illustrates the development, implementation, and assessment of the impact of a place-conscious, informal STEM program curriculum to increase STEM interest for rural youth. Drawing from research regarding best instructional practices in informal education, the study will examine the efficacy of three specific instructional methods to increase STEM interest:

1. Participation in rural-based hands-on STEM activities (National Research Council, 2015)
2. Interaction with invited scientists and community members to share rural-based STEM knowledge (Kekelis & Joyce, 2014)
3. Participation in the development of rural STEM culminating projects (Buxton, 2010)

This study examined the approach of applying place-conscious pedagogy to STEM content to enhance STEM interest. STEM is the application of multiple disciplines simultaneously and harmoniously to solve problems in everyday and extraordinary situations. As indicated by *The National Science and Engineering Report*, several methods to increase STEM interest include "promoting personal relevance . . . and situating the investigation in socially and culturally appropriate contexts" (National Academies of Sciences, 2019, p. 281). Flick and Lederman (2004) indicated that future research should incorporate cultural contexts, such as rural applications and inquiry methods, to generate STEM interest. This would allow participants to view STEM within their community and determine how it applies to everyday occurrences and generate STEM interest.

Therefore, the aim of this study was to examine the effectiveness of different instructional methods on STEM interest development for rural youth, ages eight to twelve, in an informal place-conscious STEM program. The following research question guided the study: What do youth words and actions tell us about the effectiveness of hands-on activities, role models, and culminating projects to increase STEM interest?

Background

Place-Conscious Pedagogy

Gruenewald and Smith (2014) noted that place-based design had been widely adopted, focusing curriculum on a place or community, albeit lacking human connections with a place. The place-conscious approach includes the cultural connections foregrounding the importance of local geography while also considering additional location factors that have sociological effects (Greenwood, 2013; Howley et al., 2011). Place-consciousness correlates with a pedagogy of place, referencing how a place can teach individuals about the world, how the occupants fit in the world picture, and how people identify themselves with a place (Gruenewald, 2003a; White & Corbett, 2014). Applying place-conscious pedagogy allows educators and students to inquire about their surroundings and act in their space, whether "local, regional, or global" (Gruenewald, 2003b, p. 637).

To fully embrace a place-conscious pedagogy, educators should be mindful of aligning three factors: natural history, cultural journalism, and action research (Gruenewald, 2003a). Natural history can be established by asking subject-oriented questions about the community. Greenwood (2013) uses the question, "What happened here?" to guide the inquiry of historical discovery (p.97). Cultural journalism can link young and older members of the same community, where the younger member gathers direct knowledge from the more experienced member on a particular topic (Gruenewald & Smith, 2014). When educating youth, emphasis should be placed on considering more than just observations of their surroundings. Youth need to understand their surroundings' local history, specifically from the community members (Simmons et al., 2022). To bring the connection full circle, educators should guide participants to observe their communities and hear cultural and historical accounts about their observations. With this knowledge, they could decide if they want to act. This is considered an ethical dimension, guided by the question, "What should happen here?" (Greenwood, 2013, p. 97).

To illustrate the connection between a place and its members, researchers would gain insights by using local funds of knowledge. Funds of knowledge are described as the skills and awareness developed over time and within society to allow an individual or household the ability to function within the culture (Moll et al., 1992). It has been noted that the participation gap of current students could be reduced by "reclaim[ing] local knowledge and the educational value of experiences in local communities" (Gruenewald & Smith, 2014, p. 355). The gap refers to students who are not interested in educational content and therefore not participating or achieving in classrooms. As indicated in the international study based on Programme for International Student Assessment (PISA), "prior informal science learning has a positive effect . . . and direct influence on science performance" (Tang & Zhang, 2020, p. 598). Therefore, funds of knowledge can be leveraged to help individuals gain insight and connect to educational content.

Place-conscious pedagogy demonstrates the ability to infuse natural history and cultural journalism along with funds of knowledge and action research into a STEM curriculum that captures an individual's attention and potentially increases their interest. Additionally, place-conscious pedagogy arouses interest by focusing on an individual's interest in their community context, thus influencing their situational interest (Rotgans & Schmidt, 2018). As Azano (2011) states, students are more engaged if curricula are relevant to them and "affirms their competencies" (p.2). These empirical studies point to increasing STEM interest through place-conscious inclusion of STEM content with similar ways of knowing.

As previously noted, place-conscious contextualization of STEM connections has increased interest and closed the gender gap in interest (Häussler, 1987). An emerging theme in the literature points to girls' lack of interest in STEM, which results in a less diverse STEM representation overall (Hill et al., 2010). In addition, a nationally representative longitudinal study for elementary students focusing on math interest indicated girls are less interested in math from third to eighth grades but not at a significant level (Ganley & Lubienski, 2016). Some experts have suggested that if math content were purposefully intertwined with science, engineering, or technology, girls would discern a useful purpose to math content (Cooper & Heaverlo, 2013). By furthering this idea with the incorporation of place-conscious pedagogy and informal programming, girls, as well as boys, may develop significant STEM interest.

Informal Programming

The Center for the Advancement of Informal Science Education (CAISE) defined facets in informal science as learning beyond the classroom with a limited-duration program in collaboration with other institutions that often results in resources that can be used by others (Miller, 2012). The National Research Council (2015) noted that most definitions focus on science institutions, such as museums or science centers; however, community-based programs are becoming an essential infrastructure for STEM learning. Dierking et al. (2003) observed that science learning outside of school, such as community programs, lack empirical studies compared to museum-like settings. In informal program evaluation guidelines, particular attention has been paid to "cultural competency," attention being given to the location of participant representation and the effects on the assessment protocol (Allen et al., 2008, p. 73).

Instructional Methods

Previous research has identified several instructional methods that have generated positive outcomes in informal programs (National Research Council, 2015; Shah et al., 2018). Three of the most studied instructional methods are hands-on activities (Holstermann et al., 2010); interaction with role models (Kekelis & Joyce, 2014); and the development of culminating projects (Buxton, 2010).

Hands-On

Instructional resources for informal programs characteristically contain hands-on activities, regardless of environment type (Allen et al., 2008). The activities require a participant's active physical involvement or manipulation (Flick & Lederman, 2004). Additionally, research has shown that situational interest/short-term interest can be fostered through hands-on activities and can maintain individual interest (Palmer et al., 2017; Renninger & Hidi, 2011).

Role Models

Research has demonstrated that role models influence the development of sustained STEM interest (National Research Council, 2009). A review of rural science education recommended nurturing dialogue between individuals, such as role models, in the community and their connection to STEM to increase students' value of rural knowledge and their connection with the STEM context (Avery, 2013). Many programs evaluated for increasing STEM interest included a STEM role model, specifically a role model qualified as a subject area expert and educated in cooperative learning approaches (National Research Council, 2009). Furthermore, the same report concluded that role models and other social supports "play a critical role in supporting science learning," including supporting interest, building relationships and collaborations, developing community science knowledge, and building enthusiasm (National Research Council, 2009, p. 5). Research examining the inclusion of scientists as role models found that participants need to perceive these individuals as similar to themselves, where role models share their same gender, culture, or community values, or have similar hobbies and interests (Britner & Pajares, 2006; Renninger et al., 2015). A review of rural science education recommended nurturing dialogue between individuals in the community and their connection to STEM to increase students' value of rural knowledge and their connection with the STEM context (Avery, 2013). Children often learn science concepts in typical daily interactions with their rural community role models Avery & Kassam, 2011).

Culminating Projects

Historically, inquiry-based scientific education was geared toward student interest projects, including social and scientific relevance (Flick & Lederman, 2004). A national report on science and engineering indicated that cognitive engagement through artifact creation led students to high-interest levels in science (National Academies of Sciences, 2019). In rural science educational pedagogy, photo documentation allowed participants to share their local knowledge and connect science content to their community (Avery, 2013). Along the same lines, a research study with rural girls and science projects that were student-designed and involved community issues led to participants' continued STEM interest (Ginorio et al., 2002).

STEM Interest

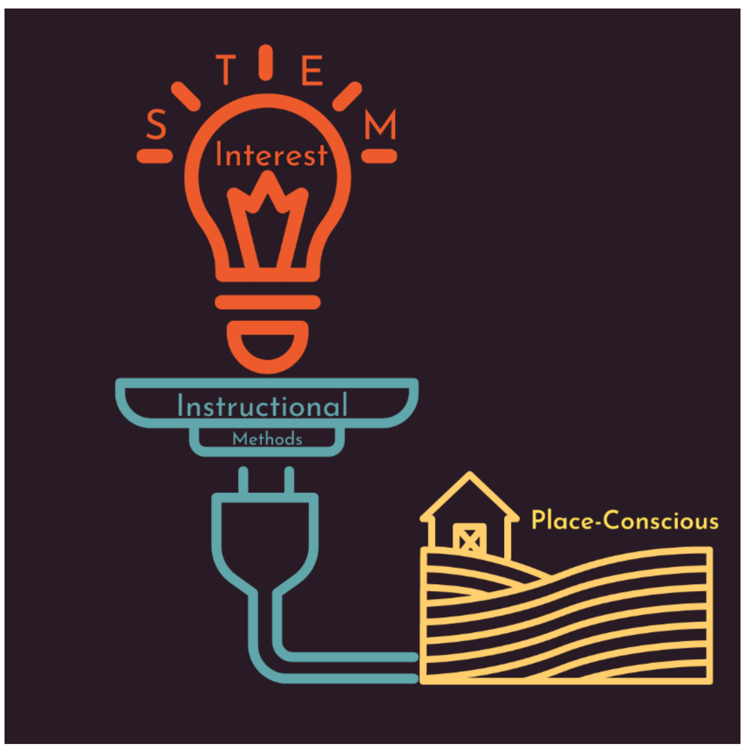
Informal learning programs "allow for the extended pursuit of learning agendas, the refinement of interests, the sharing of relevant learning resources and feedback, access to future learning experiences, and opportunities to be identified as having science-related interests" (National Research Council, 2009, p. 44). Interest, an influential factor in teaching and learning, has been explored for over 100 years yet remains elusive to researchers. A resurgence of research has been predominately geared toward its generation with text (Hidi, 1990). In research, interest has been described as having affective and cognitive components that help to increase student motivation to learn and increase understanding of the content (Silvia, 2008).

Conceptual Framework

This study is to identify the impact of various instructional methods in an informal place-conscious STEM curriculum to increase rural youth's STEM interest. This framework has been informed by several theories, including those undergirding learning in informal contexts (Rogoff et al., 2016); the role of place-conscious pedagogy (Gruenewald, 2003b); and constructivist theories regarding how children develop STEM interest (Lent et al., 1994). (See Figure 1). By identifying place-conscious STEM factors prior to curriculum development, these STEM topics can be used to inform the informal STEM program's development and give a personal linkage to the participants' culture.

Figure 1

Conceptual Framework Relating Place-Consciousness, Informal Program, and STEM Interest



Informal contexts are less about didactic instruction and more closely structured to explore subjects (Rogoff et al., 2016), allowing interest to develop by extrinsic and intrinsic factors. An informal program design allows for exploring youth STEM interest development based on instructional methods of an informal STEM program. Additionally, informal programs have indicated participants' benefits as feelings of accomplishment, building confidence, camaraderie, and exposure to new opportunities (Denson et al., 2015), which supports interest development, such as situational interest to individual interest (Hidi & Renninger, 2006).

In this conceptual framework, interest develops from the participant's interactions with the curriculum in the following ways. First, place-consciousness can develop situational interest with novel stimuli from each particular community and influential community role models (Harackiewicz et al., 2016; Hidi & Renninger, 2006; Renninger, 2009). This can lead to personal interest through topics relevant to their community's culture and participants' prior community knowledge (Harackiewicz et al., 2016; Hidi & Renninger, 2006; Howley et al., 2011; Renninger, 2009). Additionally, the place-conscious design supports the development of "action research" (Gruenewald, 2003b), which achieves relevancy to a goal (Harackiewicz et al., 2016; Renninger, 2009). Next, informal attributes of problem discovery, collaborative groups, hands-on engagement, and role model interactions tie to factors increasing situational interest (Hidi & Renninger, 2006; Maltese & Tai, 2010; Renninger, 2009). Furthermore, the personal interest could develop in informal contexts through positive emotions and information discovery about a topic (Hidi & Renninger, 2006; Renninger, 2009). Finally, combining informal learning practices with STEM content lends itself to situational interest through hands-on STEM activities and influential role models such as scientists (Krapp & Prenzel, 2011; Master & Meltzoff, 2020; Renninger, 2009; Rotgans & Schmidt, 2014). Similarly, prior knowledge could increase personal interest and raise competency and achievement in STEM topics (Howley et al., 2011; Renninger, 2009; Rotgans & Schmidt, 2014). Together, these components may increase youth interest in STEM.

Methodology

A case study design using multiple data collection methods (Bloomberg & Volpe, 2018; Yin, 1981) was employed to best answer the research question to gather and analyze qualitative data (Graue & Walsh, 1998). This is an ideal approach because it "aligns with interpretive constructivist philosophy" (Bloomberg & Volpe, 2018, p. 50; Merriam, 2009; Stake, 1995) and helps to document rural youth's perspectives on the effectiveness of three instructional methods embedded in this work to increase STEM interest in an informal place-conscious STEM education program (Creswell, 2007). Qualitative data collected through observations and surveys allowed the researcher to discover and explain some of the complexity inherent to youth STEM interest development and how it can be supported through specific instructional methods (Bloomberg & Volpe, 2018). Primary data was collected with focus group interviews and provided an opportunity for youth to describe if and how the instructional method effectively supported their STEM interest development. Secondary data sources, observations, and self-report surveys provided an opportunity to present "converging lines of inquiry," which corroborated evidence from multiple sources (Yin 1994, p. 92). As noted by Polit and Beck (2010), "The goal of most qualitative studies is to provide a rich, contextualized understanding of human experience through the intensive study of particular cases" (p. 1452). Aptly, the goal of this study is to generate a rich description of the effectiveness of instructional methods to support rural youth's STEM interest in the context of an informal place-conscious STEM program.

Research Context

This study was conducted in the northwestern United States in a state that contains the largest number of rural school districts in the country (Showalter et al., 2019; Showalter et al., 2017). Many districts contain only one school building for the K-12 student body, which serves a large geographical area. The geographical locale for this study had a county population density of 2.1 individuals per square mile.

The National Center for Education Statistics (NCES) rural-remote classification identified schools for this study. This NCES definition states that the classification criteria of each location will be over 25 miles from the next closest town (Greenough & Nelson, 2015). Following the principles of network sampling (Creswell, 2007), the researcher identified the first district willing to participate in the study. Then, the superintendent provided recommendations for a neighboring school that would also be appropriate to host an informal program and participate in the study.

This single case study was bounded by a geographical area that utilizes a local reservoir fed by an adjoining creek as a primary water source. The study was conducted in two school districts, each with one school building and both within 11 miles of each other. Each school contains between 35–50 students in their PK-6 population. The two districts are in a cooperative where they share basketball and volleyball teams and a band program. The upper-grade bands regularly travel to the other school for practices or travel together for games.

Some grade levels are combined into one classroom in each school to accommodate the small populations and maximize classroom efficiency. Each school in this study has combined classrooms for the third and fourth grades and their fifth and sixth grades. Their class sizes range from three to thirteen students.

The two communities are similar in composition. Each has a post office, volunteer fire department, church building, and at least one restaurant. Each town comprises approximately one or two blocks of businesses along the main street. The area between the two sites is comprised mainly of ranches and farms. The drive between the two is on long winding country roads, part paved and part gravel, crossing a one-lane bridge over the river and split by rocky mountainous outcroppings. It is typically dotted with white-tail and mule deer, antelope, elk, pheasants, ducks, and geese. The ranches and farms consist mainly of fields of hay and livestock, Angus cattle, and horses. Besides farming and ranching, this community's primary industry consists of a few talc plants. Both rural communities share a backdrop of scenic mountain skylines and a county border.

Currently, neither school has a comprehensive after-school program. One location previously offered a study hall but not a structured program for its youth. Geographic and student busing limitations impact the ability for these schools to provide after-school programming. Limited funding and human resources also prevent offering a regular informal program.

An Informal Place-Conscious STEM Program

In order to develop an informal place-conscious STEM program, a program should start with the core of gaining insight into funds of knowledge, and a more profound understanding is through the community. One approach to connecting with the community might be a "Rural Community Walk" (Downey, 2021). This structured learning experience can help cultivate funds of knowledge within a place by examining preconceptions and developing new understandings about place and community. Researchers recommended that for those seeking to develop a place-conscious program, funds of knowledge afford a deeper understanding of the participant and community member perspectives (Avery & Kassam, 2011; Azano et al., 2020; Downey, 2021). Furthermore, as noted by Bang and Medin (2010) there is a “critical departure from the deficit lens which views community-derived knowledge as an impediment to learning academic STEM content” (p.1009). These funds of knowledge are applied in an informal STEM program and provide opportunities to connect with youth’s own experiences (Renninger et al., 2015).

To further develop community knowledge, it is crucial to understand the history and current STEM issues facing rural communities. A practical way to discover this information is to ask community members for their input and perspectives through semi-structured interviews and informal inquiry grounded in public-facing documents (Montana State Legislature, 2018a, 2018b). These sources provide vital insights into locally relevant STEM topics that would be most appropriate to serve as the basis for curriculum development. Formal qualitative interviews with an extension specialist, a rural community member, and a state legislator identified several relevant topics related to crops, drought, and wildfires. Further exploration through informal community conversations with each site’s superintendent revealed that water was a priority issue for the community. Thus, the topic selected as the focus for the curriculum developed for this study was farming and ranching water sources. The unit’s design was developed in conjunction with an engineer and fellow scientists to incorporate their areas of expertise. This component incorporates STEM influences on transporting water for use in irrigation, such as pumps and water sources known to the area.

The water unit in this informal program was delivered through three lessons using three distinct informal instructional methods: (a) hands-on activity, (b) role model discussion, and (c) a culminating project. The content was delivered every other week over a six-week timeline. An adult volunteer and a pre-service science educator facilitated each informal program lesson. Each lesson was scripted and piloted in a summer camp to ensure fidelity between the two sites. Each youth received a STEM journal and was prompted to record their reflections and thoughts during and after each lesson. Journaling has been shown to increase interest when paired with other activities for informal STEM programs (Ardoin et al., 2014).

The hands-on lesson included the building and testing of a water pump. This instructional method was presented as an inquiry with little instructional assistance. The youth were placed in groups of three, given an iPad with an instructional video (https://www.instructables.com/How-To-Make-A-PVC-Water-Air-Vacuum-Pump/), a bag of PVC pieces and PVC pipes, and two buckets, one of which one was filled with water. The students were instructed to build a pump with the given materials by watching the video. Additionally, they were instructed to move the water from one bucket to the other bucket with their constructed pump. They were able to test and calculate their pump’s flow rate with water by timing the flow from one bucket to another. They recorded some of their results in their notebooks. This allowed them to simulate the effort required to move water from one location to another.

Lastly, they were asked to reflect on where they have seen pumps or other means of moving water in their community. These reflections in writing or drawing were recorded in their STEM journals. The purpose of the hands-on activity was to simulate the engineering process and gain a deeper understanding of problem-solving. In alignment with the place-conscious pedagogy of natural history (Gruenewald, 2003b), this instructional method demonstrated the communities' connections and issues with water sources.

The STEM role models recruited for this study were STEM career individuals whose expertise aligns with the curricular unit. Initially, these role models assisted in curriculum design and program implementation. All identified STEM role models were invited to participate in training to support their communication with elementary school students. Hour-long training sessions were based on Techbridge's Role Models Matter Toolkit (https://www.techbridgegirls.org/rolemodelsmatter/toolkit/) to support the ability of role models to engage in relatable and child-friendly dialogue (Kekelis & Joyce, 2014). The researcher was a trained facilitator for Techbridge's Role Models Matter Toolkit and guided the STEM role models through the training process. The individuals recruited for the program lesson were one male and one female, which balanced the gender representation. These local community members experienced in the STEM topic, irrigation, were invited to share their experiences. Local farmers and ranchers have first-hand local knowledge relevant to water and were able to share insights from their lived experiences connected to a previous rural community assessment and funds of knowledge specific to the community. This knowledge, shared by STEM experts, can connect academic knowledge to local experience.

In the role model lesson, youth were placed in groups of two and given a prewritten question to guide the discussion with the role models. Accordingly, other impromptu questions naturally evolved in the discussion. The purpose of this session was to discuss the STEM relevance and connection to their local community, in alignment with the place-conscious pedagogy of cultural journalism (Gruenewald, 2003b); this instructional method centered on the role models and community members' discussion to deepen the understanding and issues of community water sources.

In the third instructional method, culminating projects, youth were placed in groups of two. They were invited to take photographs relating to their interpretation of pumps and irrigation in their community. Some provided the researcher local community water pictures, and others gave directions on which local waters source pictures they wanted, and the researcher provided these pictures. Each group was provided a laptop with access to Google Docs and a template for building a poster with suggested headings and a picture file. The headings were

1. Name and School or Town
2. Introduction–What I knew before about water
3. Pump Building–What I learned
4. Community Role Models-–What I learned
5. What I think about water now
6. What I think others should know.

Groups responded under each of the headings and selected pictures to add to their poster. Posters were printed and delivered to the school sites a week after the project was completed.

Culminating projects incorporated their photographs of community STEM connections and personal reflections from the hands-on activity and the role model discussion. The purpose of this instructional method was to relate all of their reflections and experiences and provide an opportunity to share with their community. In alignment with place-conscious pedagogy of action research (Gruenewald, 2003b), this instructional method served as a platform for how youths' self-generated water data could help solve local community water sources and connect to similar global water issues.

Data Analysis

The data analyzed in this study were drawn from researcher developed observation protocol and focus group interview data and was analyzed using NVIVO™ software. Interest codes were determined a priori and loaded as nodes for both data sets into the software. Each participant was identified with attribute codes to anonymize them except for location, gender, and grade. Videos for each focus group interview was transcribed and coded a priori using 16 interest codes Renninger & Bachrach, 2015). Each transcript was reviewed multiple times to ensure accuracy and revealed two additional emergent interest codes.

Additionally, the observation protocol was developed based on the interest activity research conducted by Renninger and Bachrach (2015), who suggested analyzing observation data by activity level. Therefore, interest activity codes were generated to code observations with a value reflecting high, medium, or low activity levels. This produced a total score for each interest activity code. These observations also contained researcher reflection notes headed by activity interest codes for each session.

Frequencies were generated for the observation and focus group interview codes. The frequencies were used for pattern evaluation to represent the impact of each instructional method on STEM interest. Multiple representations were used to provide similar and different views of the same data (Pagano & Dolan, 2014). As noted by Sandelowski et al. (2009), quantization of data to evaluate for treatment or variable differences, in this case, instructional method, has been found to give researchers the ability to "discern and to show regularities" in qualitative data (p. 3). Therefore, data were organized into two categories: a) physical interest indicators and b) emotional interest indicators. The data in each category were then partitioned into four naturally occurring clusters – labeled many, some, few, and very few – to represent the frequency of participants' responses or actions about STEM interest. This partitioning process was conducted relative to the set of participants' responses or actions for each method. Given the different number of total responses for each instructional method, the qualitative labels represent a different percentage range for each method. All responses that fell into the "many" cluster were determined to be meaningful indicators of STEM interest. Thus, the data from focus group interviews and observations generated themes that spoke to the impact of each instructional method. Participants' quotes provided additional contextual details to tell a rich, detailed story of how interest developed during each instructional method.

Results

Effectiveness of Hands-On Activities on STEM Interest

Hands-on activities increased STEM interest through opportunities for collaboration. The youth were observed actively working together to build a pump with little direct instruction. They were focused on the hands-on build of the pump and observed putting together and taking apart the pump many times. Many participants did this until the pump moved water to the second bucket. The youth noted that the activity was challenging and was only successful if all group members worked together. They noted that their previous building experiences assisted them during the hands-on STEM activity. A participant commented on her group building issues: "One of the tips that my dad always told me when I was helping him work on cars is every time, righty tighty lefty *loosey because they [group partners] were trying to figure out how to twist it on the right way."* Some youth recalled previous building stories of their family members that connected to positive feelings about their building success.

STEM interest was expressed in multiple ways by participants. They were challenged by the pump building and left to figure out the build with limited resources. They were skeptical that a bag of PVC parts and PVC pipes would become a pump. As stated by participant, "I never knew you had to have all those parts to build one." They expressed interest in working in groups stating conflicting opinions about whether to work alone or with others. They were interested in the act of building with their hands. They conveyed emotions of happiness, surprise, pride, excitement, and anger in conjunction with building the pump and working in their groups. They also discovered some of the physics involved in moving the water. A participant stated, "I did not know that using so much force could make like water go into another bucket." They expressed interest in learning from mistakes, similar to a challenge or growth mindset (Dweck, 2008). These emotions and challenges are expressed by a participant, "*Like sometimes we get things wrong and then it's like, oh, I got it right, you kind of feel like YAY* [emphasis added]!" STEM interest was generated by collaboratively working together through the informal method of hands-on and the inquiry pedagogy while emphasized by the challenge and emotions of the youth. The table below displays data analysis of the focus groups.

Table 1

Frequencies and percentages of variables coded during focus group from transcripts.

Instructional Method			
Hands-on			
Interest Variable	**n**	**%**	**Category**
Autonomy: Independence	2	1.90	Few
Challenge: Belief Conflict	26	24.76	Many
Computer: Technology	2	1.90	Few
Group Work: Interactive Effort	26	24.76	Many
Hands-on Activity: Physical Participation	21	20.00	Many
Instructional Conversation: Meaning Clarification	9	8.57	Few
Novelty: New and Unusual	14	13.33	Some
Personal Relevance:Self Connection	5	4.76	Few
Activity Codes (N)	**105**	**100**	
Activity Level: Engagement Level	24	18.32	Some
Awareness: Insight	25	19.08	Some
Emotionality: Feeling	38	29.01	Many
Independence: Individual Effort	15	11.45	Some
Mood: Affective State	0	0.00	None
Openness: Willing	8	6.11	Few
Reactivity: Behavior Change	0	0.00	None
Sociability: Collective Relation	21	16.03	Some
Character Codes (N)	**131**	**100**	

Effectiveness of Role Models on STEM Interest

The main finding for increasing STEM interest during the role model instructional method was discovering new community knowledge. The participants were particularly interested in the discussions about local water-related activities, including drilling wells and examples of ranching and farming pumps. Additionally, they were interested in writing their thoughts about the discussion, especially the younger participants, who enjoyed writing in their science notebooks. As expressed by a participant, “I like when we get to do writing projects, you know what that means in general, and you have and try to figure it out; by ourselves most.”

The youth appeared to be cognitively engaged at a higher activity level when understanding concepts explained by the community role models. They express mostly positive emotions about the ability to write during the role model activity, although once described themselves as “*happy with a sprinkle of bored [emphasis added]”* when needing to sit and listen. The novelty of the information was of interest to them, as noted by their comments and questions about drilling under the ground to reach the water. Many participants were able to connect the information to their home and community experiences and sometimes to future events like starting their family farm, which is also an indicator of interest. They were interested in learning new information and its relevance to their community, especially concerning ranch animals and people. A participant states this as, “Yes, it’s clean for animals now, OK, but it’s not it’s not cool for people. Well, it was farther down, people want that water farther down.” They were aware of the personal relevance of their education and future needs of STEM knowledge. WB4 explains, “Maybe it can help them find a job, but they hope it can help them understand more so that if they know about it, they have a good chance at the job.” Youth were interested in knowing more and actively engaged in constructing an understanding of the STEM water information for themselves. Table 2 below displays data analysis from focus groups.

Table 2.

Frequencies and percentages of variables coded during focus group from transcripts.

Instructional Method Role Model			
Interest Variable	**n**	**%**	**Qualitative Category**
Autonomy: Independence	7	10.7	Some
Challenge: Belief Conflict	7	10.7	Some
Computer: Technology	2	3.08	Few
Group Work: Interactive Work	5	7.69	Few
Hands-on Activity: Physical Participation	5	7.69	Few
Instructional Conversation: Meaning Clarification	9	13.8	Some
Novelty: New and Unusual	21	32.3	Many
Personal Relevance: Self Connection	9	13.8	Some
Activity Codes (N)	**65**	**100**	
Activity Level: Engagement Level	26	40.00	Many
Awareness: Insight	7	10.77	Some
Emotionality: Feeling	24	36.92	Many
Independence: Individual Effort	3	4.62	Few
Mood: Affective State	0	0.00	None
Openness: Willing	1	1.54	Very Few
Reactivity: Behavior Change	0	0.00	None
Sociability: Collective Relation	4	6.15	Few
Character Codes (N)	**65**	**100**	

Effectiveness of Culminating Projects on STEM Interest

The main finding for the culminating project is represented as active research (Gruenewald, 2003b), a component of the place-conscious theoretical curriculum framework. The youth were interested in presenting the posters they created with their community. This STEM interest effect was the desire to work preparing and presenting the newly acquired knowledge actively. This included a desire for sharing that STEM knowledge with others in their community. A study sponsor had indicated the resulting posters could be publicly shared in a future event with their organization. As stated by a participant, "Because knowing that a lot of people are going to see it and you're going to see how much kids can really do." Another interesting finding during this third instructional method was how it correlated to the first two instructional methods. Meaningful interest codes were repeated from the hands-on and the role model sessions. This aligns developing STEM interest with instructional methods. The hands-on and culminating project shared most interest development through group work, whereas the role model and culminating project shared the majority of interest development through personal relevance.

This finding is supported by expressing many emotions, including happiness, pride, and excitement about designing posters and presenting them to their community. They showed physical and verbal signs of enjoyment during and after making their posters. Several individuals expressed being proud of creating a poster and presenting it to adults. A participant stated "*knowing that like the whole, like a lot of people could see it [emphasis added].*" There were mixed opinions of working alone or working in a group. The participants were interested in the autonomy of presenting their culminating project to an audience but equally interested in working with a group to develop the posters. They appeared to have deep knowledge of their partners since they attended school together. Some were aware of difficulties with specific individuals, and some noted strengths and comfortability with other individuals. A participant explained, "Not fun because of my partner, he is tired in the afternoon," which is contrasted by another individual, "I'm glad because of my partner, because I've known him since I was in this school . . . I really enjoy it and relax a little bit. So, I have fun." They were interested in working with computers and learning new technology skills because of the higher cognitive and physical engagement of creating a digital poster. They were able to draw from their past STEM experiences. They used their STEM experiences to fill their poster content, indicating an interest variable of awareness. Youth also noted their interest in their aspirations, as stated by one participant, "it made it more interesting to make stories, made me want to be an author one day." They are interested in trying new things, demonstrating openness. Another participant stated, "I stepped out of my box, and I feel that I didn't feel I was nervous or not nervous to try something new again, to try new things." Interest development was more varied and demonstrates how the culminating project compounds interest development. Table 3 below displays data analysis from focus groups.

Table 3.

Frequencies and percentages of variables coded during focus group from transcripts.

Instructional Method			
Culminating Project			
Interest Variable	**n**	**%**	**Qualitative Category**
Autonomy: Independence	12	18.18	Many
Challenge: Belief Conflict	8	12.12	Some
Computer: Technology	7	10.61	Some
Group Work: Interactive Work	9	13.64	Some
Hands-on Activity: Physical Participation	5	7.58	Few
Instructional Conversation: Meaning Clarification	8	12.12	Some
Novelty: New and Unusual	2	3.03	Few
Personal Relevance: Self Connection	15	22.73	Many
Activity Codes (N)	**66**	**100**	
Activity Level: Engagement Level	23	20.91	Many
Awareness: Insight	22	20.00	Many
Emotionality: Feeling	26	23.64	Many
Independence: Individual Effort	9	8.18	Few
Mood: Affective State	0	0.00	None
Openness: Willing	16	14.55	Some
Reactivity: Behavior Change	0	0.00	None
Sociability: Collective Relation	14	12.73	Some
Character Codes (N)	**110**	**100**	

Overall Analysis

STEM interest was affected in different and similar ways throughout this project. Interest developed similarly through emotions across all three instructional methods. During the hands-on instructional method based on the natural history component of place-conscious design, STEM interest developed from group work, hands-on, and challenge. During the role model instructional method based on the cultural journalism of place-conscious design, STEM interest developed from personal relevance and novelty. During the culminating project instructional method based on action research of place-conscious design, STEM interest grew from similar previous sources of group work and personal relevance and differently through autonomy and computers and technology. Please see Table 4 for meaningful STEM interest indicators during the overall study. Finally, these STEM interest findings indicate that an informal place-conscious curriculum can cultivate short-term situational interest. Future research should explore how this situational interest can be further developed into a longer lasting individual interest for the same individuals.

Table 4

STEM Interest Indicators

Informal Instructional Method	Place-Conscious Pedagogy	Main Finding	STEM Activity Interest Indicators	STEM Characteristic Interest Indicators
Hands-On	Natural History	Collaboration	Challenge *Group Work* Hands-On	**Emotionality** *Awareness*
Role Model	Cultural Journalism	New Community Knowledge	Novelty *Personal Relevance*	**Emotionality** *Activity Level*
Culminating Project	Action Research	Action Research	*Group Work* Autonomy Computer/Technology *Personal Relevance*	**Emotionality** *Activity Level* *Awareness*

Italicized* indicators show overlap in two instructional methods and **bold indicators show repetitions in all instructional methods.

Conclusions

Contributions to the Literature

Previous research has outlined five characteristics of students' interest development identified in this study (Renninger & Hidi, 2011). First, interest is specific to an object or content (Renninger & Hidi, 2011). In this current study, the culminating project demonstrates that the youth were interested in their communities' critical environmental factor, water. Furthermore, this illustrates the importance of a place-conscious curriculum Greenwood, 2013) as a significant factor in generating STEM interest.

Second, interest relates a person to their environment, and this interaction sustains this interest (Renninger & Hidi, 2011). In the current study, the informal STEM program took over six weeks allowing for time to reflect and notice water and pumps in their community. Youth revisited community water sources and engineering practices to interact with the content and build their interest (National Research Council, 2009).

Third, interest is displayed and observed in cognitive and affective ways (Renninger & Hidi, 2011). In the current study, an overarching emotional interest indicator was noted during all of the instructional methods while different cognitive components were evident in each instructional method. Youth were able to use their knowledge in each instructional method while noting their interest feelings.

Fourth, previous research suggests that some younger individuals are not always aware of their interests (Renninger & Hidi, 2011). This was supported in the current study, as even when they were frustrated during an instructional method, they still indicated interest through their actions and words. This could be seen in the hands-on instructional method where youth were challenged to build a pump but displayed positive emotions when moving water from one bucket to another. Informal learning is designed to give youth the ability to inquire and enjoy (National Research Council, 2009) while being personally relevant (Greenwood, 2013).

Finally, interest has a physiological and neurological difference when a person is interested in content (Renninger & Hidi, 2011). This was most evident during the culminating projects component of the program when youth were drawing on previous experiences and knowledge they had acquired during earlier instructional methods.

Overall, their sustained interest in community water was facilitated by the place-conscious pedagogy and informal design (Greenwood, 2013). The informal approach does not have formal requirements or assessments to be met (National Research Council, 2009). Youth expressed their desire to share their knowledge even though there was no requirement. These study findings align with the five characteristics of interest development, and the study provides specific active and characteristic indicators that an informal place-conscious STEM program can develop interest in rural youth.

Future recommendations

Future studies should include project extensions of community presentations to examine individual STEM interest development and longitudinal follow-up research to explore situational STEM interest development. Additionally, directions for future work include thoughtful timing of the project within the school day and community relationship-building to assist with the recruitment of role models for cultural journalism with place-conscious pedagogy. This research provides a foundation for future work to extend these findings and develop additional pedagogical methodologies for informal and place-conscious designs.

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About the Author

Elaine Westbrook, EdD, is an assistant professor of STEM Methods in the Department of Theory & Practice of the College of Education at Montana State University Billings. Before her work in higher education, Dr. Westbrook was a chemistry and astronomy high school teacher and a two-time national delegate for Girl Scouts in Tampa, Florida. She earned her bachelor's degree in Chemistry at Kennesaw State University and her Master's in Science Education and Doctorate in Curriculum and Instruction from Montana State University. Her research interests are focused on informal education, place-conscious pedagogy, rural and indigenous communities, and upper elementary-aged youth. Her primary ambition is to raise marginalized youth's voices and develop programming that increases STEM interest.

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All Kinds of Text: Investigating a Phenomenon Through Multimodal Media

Frederick Peinado Nelson, *California State University, Fresno*

Explanations about real-world phenomena are frequently challenging for students in this time when they can ask Siri or Google for the answer to a question like, "How far away is the moon?" Many of the worthwhile scientific questions are more complex, dependent on numerous conditions, subject to individual interpretations, and requiring attention to the credibility of the resource that is answering the question. The typical approach of elementary and middle school learners to an informational text is an open-ended or exploratory one in which they read a text with attention to the main idea and supporting details. The purpose of reading is usually for the learner to look at explanations of concepts, facts, and ideas in these expository texts. In this article, we approach text using the Next Generation Science Standards (NGSS) Science and Engineering Practice of Obtaining, Evaluating, and Communicating Information to interact with a variety of information sources with the purpose of investigating a phenomenon.

***Keywords*: multimodal text, universal design, Next Generation Science Standards, phenomenon**

> *When we moved to our new house, I planted a garden, and I got some plants that I could use to make salsa. I bought some jalapeno pepper plants, some tomato plants, and a cilantro plant. But the one I was really excited about was a tomatillo! This plant would give me some delicious green fruit that I could use to make salsa verde. I planted the tomatillo near the tomatoes and peppers in a raised planter bed, and it grew quickly with regular watering in the warm spring air of central California. Soon the plant had spread out a lot in a sort of "viney" way, and had lots of yellow flowers, which the bees enjoyed visiting. I had flowers and pollinators, so the tomatillos couldn't be far behind. Little did I know, there would be no fruit on these plants. Despite the best suggestions of my friends, such as "hit the stems with a stick to loosen the pollen," and "use a little paint brush to transfer the pollen from one flower to another," not one fruit ever set. What had I done wrong?*

The situation I describe is an authentic one that I experienced and later shared with my preservice elementary teachers in the science methods class I teach. It is presented as an example of a *phenomenon* that learners can investigate using the Science and Engineering Practices (SEPs) of the Next Generation Science Standards (National Research Council, 2013). Specifically, this activity makes use of SEP 8, Obtaining, Evaluating, and Communicating Information.

In this practice, learners engage in communication skills, including critical review of information about science, considering important ideas and potential sources of error. They duplicate the actions of practicing scientists by synthesizing numerous information sources, while considering the relevance and value of each in the communication of a conclusion or explanation.

The lesson presented in this article focuses on these specific components of SEP 8 at the Grade 6-8 developmental level:

- Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).
- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.
- Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts.
- Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations (NGSS Lead States, 2013, Appendix F, p. 15).

A typical way for learners to obtain information is from reading informational text to develop connections for making sense of phenomena (Krajcik & Sutherland, 2010). These formal content sources, such as traditional textbooks, may be lacking in modes of representation other than words (CAST, 2018.). I approach text in this activity with a more inclusive and multimodal definition, agreeing that “students’ primary texts may be the physical world itself as they read landscapes, internal organs, lunar phases, or cells underneath a microscope” (Alvermann & Wilson, 2011, p. 118). My list of multimodal texts that learners explore in order to make sense of the phenomenon includes web pages, drawings, photographs, videos, blogs, and even a live interview. The activity aligns readily with the three dimensions of the *Next Generation Science Standards* (Table 1) and Common Core State Standards for Literacy.

Table 1

Next Generation Science Standards dimensions aligned to the tomatillo lesson.

<table>
<tr><td colspan="3">PE: MS-LS1-4 From Molecules to Organisms: Structures and Processes–Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.</td></tr>
<tr><td>SEP8: Obtaining, Evaluating, and Communicating Information

SEP6: Constructing Explanations and Designing Solutions</td><td>DCI LS1.B: Growth and Development of Organisms–Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction.</td><td>CCC: Structure and Function</td></tr>
</table>

Table 2

Common Core English Language Arts Standards relevant to the tomatillo lesson.

Research to Build and Present Knowledge: CCSS.ELA-LITERACY.WHST.6-8.8	Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation (California Department of Education, 2011, p. 89).
Integration of Knowledge and Ideas: CCSS.ELA-LITERACY.RST.6-8.9	Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic (California Department of Education, 2011, p. 89).

The Phenomenon

Rather than confirming a scientific principle like conservation of momentum or gathering information on a disciplinary topic like the water cycle, this investigation engages learners in examining a phenomenon. Penuel and Bell (2016) advocate for the coherence of instruction when learners confront "anchor" phenomena, including these selected characteristics:

- Builds on authentic personal or family experiences.
- Observable to students. "Observable" can be with the aid of scientific procedures (e.g., in the lab) or technological devices to see things at very large and very small scales (telescopes, microscopes), video presentations, demonstrations, or surface patterns in data.
- Can be a case, something that is puzzling, or a wonderment.
- Has relevant data, images, and text to engage students in the range of ideas students need to understand. It should allow them to use a broad sequence of science and engineering practices to learn science through first-hand or second-hand investigations.
- Has an audience or stakeholder community that cares about the findings or products (Penuel & Bell, 2016).

The phenomenon learners investigate in this activity concerns the growing, flowering, but non-fruiting tomatillo described in the introduction, which satisfies many of these attributes.

Tomatillos are a plant in the nightshade family with a small fruit, usually green. They are sometimes called husk tomatoes, due to the papery pouch in which the fruit grows. The majority of elementary learners in California's Central Valley are of Hispanic heritage, and the ingredient of tomatillos in salsa verde is familiar to them. Also, many families work in agriculture, so there are frequently rich funds of knowledge that learners bring into the classroom from the experiences of siblings, parents, and grandparents. Many features of the "life cycle" of a tomatillo can be explored through physical examination, including "dissecting" the fruit and viewing the flower and husk through a magnifier. The puzzle of "so many flowers, why no fruit?" presents an authentic challenge for learners to solve, and the answer is not found with a simple online search. Instead, learners need to consider multiple sources of information and make decisions about the relevance, accessibility, and credibility of those sources. The activity begins with a brief presentation from the gardener (me) about the tomatillo failure.

The Texts

Learners work in small groups of two or three to explore the texts. They are discouraged from asking "why" questions and instead create a set of collaborative notes that record the questions asked of each text and where the answers located. They are also encouraged to take note of the words they encounter that seem relevant or important to the phenomenon. After working on the first text for a few minutes, groups are selected to share their findings with the whole class. The discussion emphasizes the questions that the text was able to answer, with learners recognizing that the phenomenon question (Why wasn't there any fruit?) will require more and different kinds of texts to construct an explanation. I also record the important words they have identified, and then move on to the next text.

Figure 1

Honeybee (Apis mellifera) visits tomatillo flowers.

(Dartrider, 2015)

Here is the list of multimodal texts learners explore:

1. Graphic of a tomatillo plant from the label of a packet of tomatillo seeds. The image provides some brief information about planting (after the last spring frost) and harvesting (65 days from transplanting).

2. Picture of a bee and tomatillo flowers, showing the pouch the tomatillo grows in (Figure 1).
3. Link to an article about tomatillos (https://en.wikipedia.org/wiki/Tomatillo).
4. A list of garden-related online resources (select 1):
    a. Bonnie Plants Growing Tomatillos website (https://bonnieplants.com/how-to-grow/growing-tomatillos/)
    b. My Gardener's Path: How to Grow and Harvest Tomatillos (https://gardenerspath.com/plants/vegetables/tomatillos/)
    c. Gardening Know How–Empty Tomatillo Husks (https://www.gardeningknowhow.com/edible/vegetables/tomatillo/empty-tomatillo-husks.htm)
    d. Houzz Discussion Board–Tomatillos tons of flowers . . . No fruit? (https://www.houzz.com/discussions/1485346/tomatillos-tons-of-flowers-no-fruit)
5. YouTube video of a gardener talking about how tomatillos grow (https://youtu.be/hX5_kpAQ7Fc)
6. Dissection of a tomatillo. Learners have tomatillos, tomatillo flowers, plastic knives, forks, toothpicks, magnifiers, and paper plates. They are encouraged to cut into the tomatillos, examine under magnification, and make drawings of what they observe.
7. Interview with the gardener (me). I also show a couple of actual photographs of my garden, identifying the tomatillo plant. I encourage the learners to ask questions about my gardening practices, based on what they have discovered from the other texts.

After all of the texts have been explored, learners are directed to construct an explanation of the phenomenon.

The Explanation

To address the mystery of the non-fruit bearing tomatillos, learners engage in the Science and Engineering Practice of Constructing Explanations. This practice asks learners to consider "describe phenomena," use "models or representations," and "apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena" (NGSS Lead States, 2013, Appendix F, p. 11),

Learners make decisions about the communication of their explanations, selecting an appropriate mode of action and expression to demonstrate their understanding (CAST, 2018). These modes of communication may include textual, kinesthetic models, visual presentations, and other designs approved by me.

Table 3

Selected questions about the texts.

Text	Questions to Ask	Questions Remaining	Words Encountered
Tomatillo graphic	What does a tomatillo plant look like? What does the fruit look like? What are some of the growing conditions? When is the fruit ready?	How big is the plant? Does it produce fruit like other plants (tomatoes, peppers)?	Warm season Transplanting
Bee picture	How big is a tomatillo flower? Are bees attracted to the flowers? Where on the plant does the fruit grow?	What function does the bee have with the tomatillo? What is the connection between the flower and the fruit?	Pollen

More Phenomena, More Texts

This learning activity models the use of multimodal texts to investigate a phenomenon for preservice teachers therefore, the next step is to engage those future teachers in the construction of their own lessons. Phenomena for exploration include the variety of objects that wash up on a beach, the rotting of a jack-o-lantern, and the movement of sunflowers.

This approach to interrogating the text for specific answers situates the learner as an investigator, rather than more traditional assignments with a purpose to "explain events, procedures, ideas, or concepts in a historical, scientific, or technical text, including what happened and why" (California Department of Education, 2013, p. 15); often a summary of the provided text. The affordances of this lesson design provide rich opportunities for authentic investigation and connection to learners' funds of knowledge, powerful access points for NGSS.

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About the Author

Frederick Peinado Nelson, PhD, is Associate Professor of Science Education in the Department of Liberal Studies at California State University, Fresno. Dr. Nelson received his PhD in Science Education from the University of Florida in 2012, and taught high school science in Kansas for nine years. He achieved National Board Certification in 2004, which was a seminal influence on his thinking about reflection. His scholarship focuses on the development of reflection by preservice teachers and the dynamics of interdisciplinary faculty collaboration in teacher education.

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A University–Community Partnership Model to Support Rural STEM Teaching and Student Engagement

Kathleen Kavanagh, Jan DeWaters, Seema Rivera, Melissa Carole Richards, Michael Ramsdell, and **Ben Galluzzo,** *Clarkson University*

Rural economically disadvantaged communities face unique challenges in engaging students in science, technology, engineering, and mathematics (STEM). School district administrators, teachers, and students do not have access to high-quality STEM opportunities compared to urban schools. This article describes a partnership between a small, private STEM university and a network of school districts scattered across the geographically isolated region of upstate New York. The partnership's primary goal is to support the teaching and learning of STEM. This is achieved through actively engaging a range of university and community stakeholders in STEM enrichment and professional development. Programming includes summer camps and after-school activities, challenges and competitions that focus on inspiring students to pursue STEM careers, undergraduate and graduate student mentors, and a university curriculum designed to prepare teachers to work in high-need school districts. Activities are supported by the university's Institute for STEM Education, which fosters collaborations for like-minded faculty and campus members to pursue grant opportunities and connect with community members. The paper describes various program components and how they work to support each other, discusses impacts of the program, and describes ways in which elements can be implemented elsewhere.

***Keywords*: Rural STEM education, outreach, partnerships, competitions, K-12 outreach**

University and K-12 school partnerships create Science, Technology, Engineering, and Math (STEM) educational opportunities for K-12 students, university students, and both teachers and faculty. These collaborations have a combined purpose: to improve student outcomes and experiences. According to Robinson et al. (2017), shared attributes of quality partnerships between schools and universities include a shared vision, institutional leadership, communication and collaboration, shared ownership and accountability, alignment and sustainability, and responsiveness to the local context. This paper describes successful professional and collaborative practices between rural K-12 schools and a STEM-focused university located in the same rural region.

Rural America affords individuals the outdoor recreation spaces they seek to boat, fish, ski, hike, and more. Others may seek rural areas to be near family or friends. However, rurality has challenges in terms of educational opportunities. STEM teacher shortages that exist in most K-12 schools across the country are even more prevalent in rural areas. Recruiting and retaining teachers in rural areas is difficult; smaller communities are tied to less funding, which means lower teaching salaries, higher poverty rates, geographic isolation, and a limited pool of potential faculty applicants. For a combination of these reasons, rural areas are often seen in an unfavorable light (Aragon, 2016). Rural students tend to have fewer opportunities for engaging in STEM learning opportunities (Boettcher et al., 2022). In addition to limited resources because of limited funding, the challenges are often exacerbated by the fact that many rural areas lack access to broadband connectivity (Croft & Moore, 2019; Saw & Agger, 2021). Issues of access are worsened for students of color in rural areas (Horrigan & Duggan, 2015).

Teachers in rural schools face unique challenges. In addition to a general lack of access to materials and programming, teachers may often teach multiple subjects because there are fewer faculty and staff. At the same time, rural teachers tend to know students and their families well because they may have taught a sibling or parent of their student; many times, the school district is one of the larger employers in the area, so teachers may even know parents who work in the school. Preparing preservice teachers to overcome unique barriers in rural schools can increase equitable access to effective STEM education for rural students (Azano et al., 2019).

The community–university partnership described in this work is located in St. Lawrence County (SLC), situated in rural Northern New York State (NYS). SLC has the second highest poverty rate in NYS, at 18.9%, and nearly 27% of the county's children live in poverty (Lawton, 2021). Approximately 15,000 students in grades PK-12 are educated in 18 rural SLC school districts, including nine very small districts of only 600 students or fewer. All districts share the same problems of limited resources and significant poverty rates, with more than 50% of the students eligible for free or reduced lunch. Along with poverty, students are at risk of not completing high school or functioning below academic standards. In 2021, 13% of the population over the age of 25 had no high school diploma, and another 35% only had a high school diploma. Only 33% of the population had a bachelor's degree compared to 38% for NYS. Student achievement is impacted by regional poverty. The NYS 2018 math test data indicate that 16 SLC school districts had less than 50% of their students achieving proficiency. One school had zero students score proficiency in grade eight.

Student enrollment in upper-level math and science courses is comparatively low. The 2018–2019 NYS Education School Report Card data (NYS School Report Card) indicate that only 14.7% of SLC students were enrolled in physics, and 44.7% were enrolled in Algebra 2. The small number of students who successfully complete upper-level science and math courses translates to only a few students who are adequately prepared to enter STEM majors in college.

Clarkson University (CU), located in the heart of geographically isolated SLC, is a small, private STEM university with a long history of community outreach. CU has strengths in training STEM leaders and STEM teacher leaders with a successful Masters of Arts in Teaching (MAT) program, STEM departments, and an Institute for STEM Education. Administrative leaders committed to cultural change and a growing number of teachers with a history of engaging in STEM initiatives have paved the path for continued success. In this region where popular and traditional STEM venues such as science centers and high-tech industry are limited or non-existent, CU is a regional magnet of science and engineering excellence, partnering with local businesses, community-based organizations, and licensed professionals to offer students and teachers alternative and effective STEM content.

One of CU's early initiatives was the Project-Based Learning Partnership program funded by the National Science Foundation (NSF), which engaged over 90 partner teachers, 3100 students, and 70 SLC students, and focused on project-based modules in the classroom (Powers & De Waters, 2004). The program received national recognition for the middle school "Energy Systems and Solutions" curriculum, which won the 2009 Premier TEACH Engineering Curriculum Development Award for K-12. The program inspired the growth of outreach activity and, in 2004, created the Office of Educational Partnerships (OEP) to solidify the institutionalization of outreach at CU (Powers et al., 2008).

For several years, educational outreach activities at CU were coordinated through the OEP. The Institute for STEM Education was established in 2016, subsuming the roles of the OEP and providing the university with a larger hub for K-12 Outreach and STEM teaching support. Professors participate as affiliates or are appointed as faculty in the Institute. Two graduate student fellows support the Institute's outreach initiatives as well. Undergraduate students are recruited and trained to assist with programming, volunteer at events, and mentor high school students. The Institute also advises students in CU's pre-teaching minor, which facilitates transitioning into CU's MAT program. The MAT program is further supported by an NSF Noyce grant, which provides scholarships and training to develop high-achieving STEM college students, into STEM Teachers, preparing them specifically to work in high-need school districts. In 2021, CU partnered with 14 universities to research rurality and STEM teacher preparation, seeking to answer questions related to how teacher preparation programs prepare students to work in rural areas and what factors effectively retain STEM teachers in rural school districts.

This article demonstrates a variety of opportunities created through university–K-12 partnerships in a rural area (Figure 1). The paper describes how one university works with multiple rural school districts, sharing how the work is implemented, and the challenges, and finally providing recommendations for practice – particularly for other STEM-focused universities in rural areas. All educational programming and opportunities have certain complexities and regular practices; the intent here is to focus on specific challenges and opportunities of implementing STEM teaching and learning partnerships in rural areas, providing details for a few of CU's most noteworthy programs.

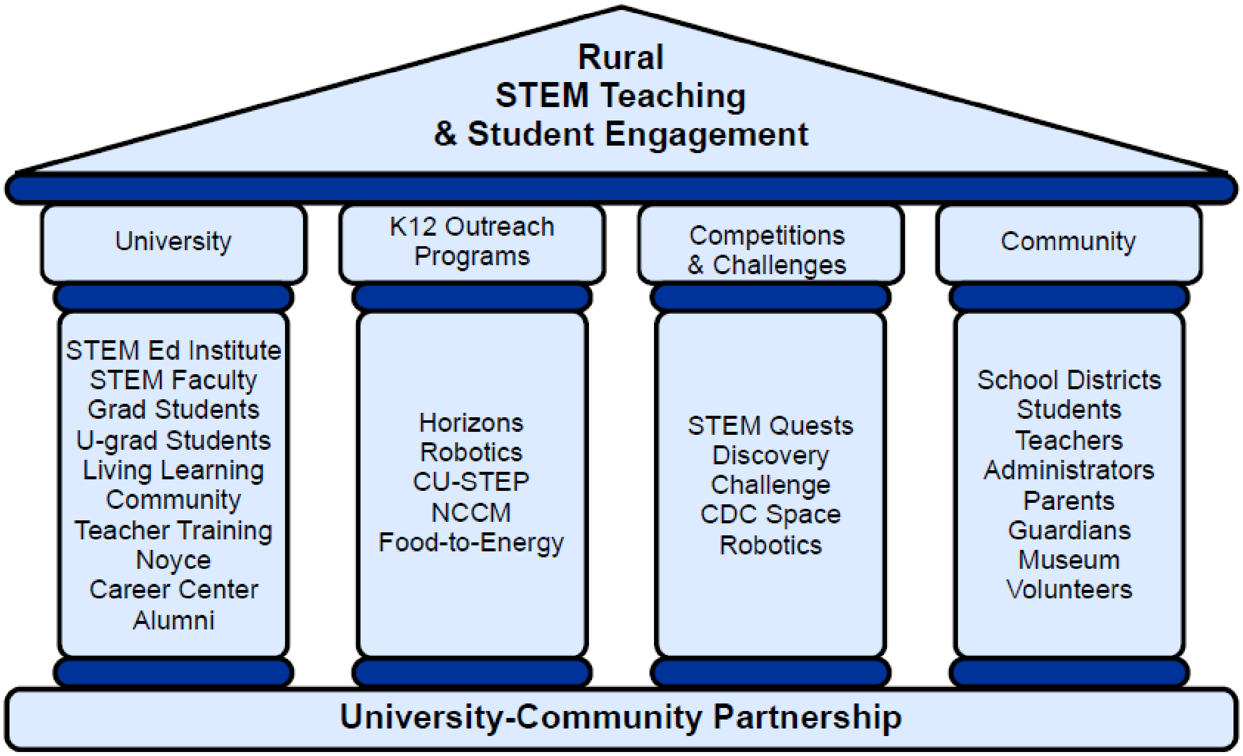
K-12 Outreach

This section highlights two prominent outreach programs, describing how they leverage partnerships to support teachers and inspire both pre-college and college-aged students. One is a grant-funded program and the other requires tuition fees, with needs-based scholarships widely available through the local Board of Cooperative Educational Services (BOCES) district.

CU's Science and Technology Entry Program (CU-STEP) has been in existence at CU since 2006 and is jointly funded by the NYS Education Department (NYSED) and the University to support approximately 200 students annually in grades 7 through 12, from 12 different school districts spread out across northern NYS. The target audience is students who are underrepresented minorities or economically marginalized students; however, the majority of students are eligible based on free or reduced lunch.

Figure 1

University community partnerships and several examples of programming that support rural STEM teaching and student engagement

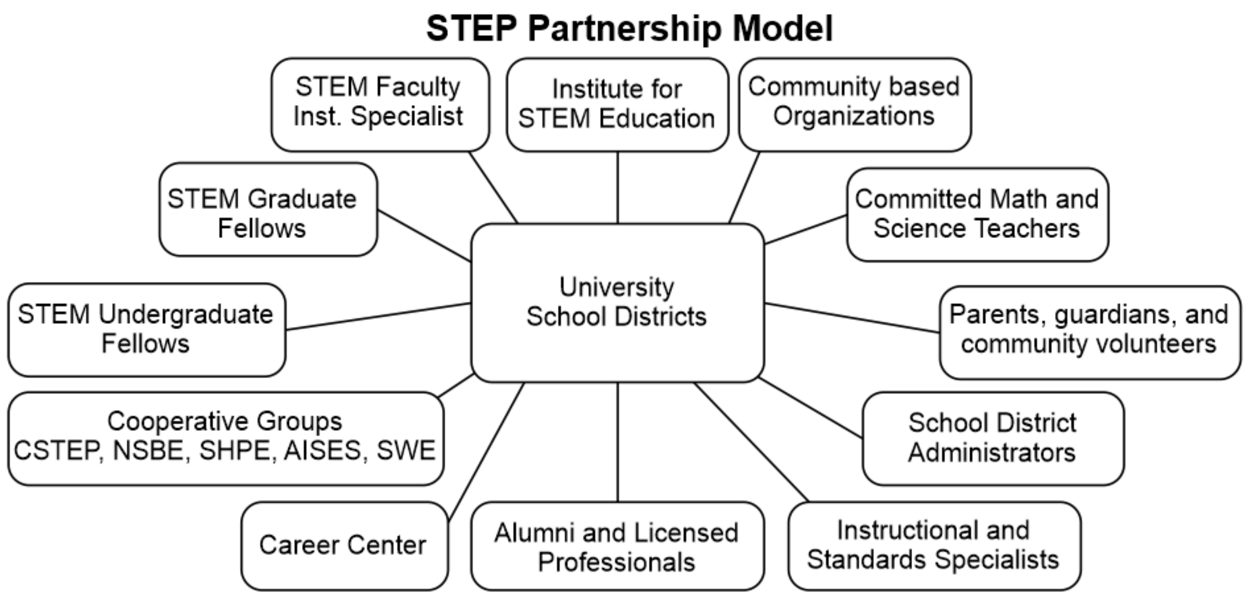


CU-STEP provides students with academic enrichment and research experience in science, mathematics, and technology content areas and consists of summer and academic year components. The program's success relies on a teacher coach in each school district who recruits eligible students and meets with them on a weekly basis. They are supported by two graduate student fellows who visit the schools once per month and assist with activities. A wide range of campus resources supports this program and strong relationships with school districts are essential in recruiting and retaining students, as seen in Figure 2.

Central to the curriculum are project- and problem-based learning principles, focusing on students being actively involved in learning through collaborations to solve a real-world problem (e.g., Kokotsaki et al., 2016). CU-STEP activities range from computer programming game challenges, conducting original research projects for a statewide competition, and interacting with college mentors and licensed STEM professionals to designing and analyzing a model roller coaster. The program's mentoring component pairs college students with participants so that they can discuss choices being made at critical times that pave their way toward college and careers (Rivera et al., 2019).

Figure 2

Partnerships in CU-STEP Model, including many campus societies: College-Science Technology Entry Program (CSTEP), National Society of Black Engineers (NSBE), Society of Hispanic Professional Engineers (SHPE), American Indian Science and Engineering Society (AISES), and Society of Women Engineers (SWE).



Once per month, the students across all school districts visit campus for a workshop that includes STEM enrichment activities, college and career readiness, or individualized research projects. These workshops are typically led by CU community members and supported by about a dozen undergraduate student volunteers. For example, the director of the Career Center created an immersive mock job fair experience where students role-play as job seekers equipped with resumes and others act as employers with the goal of finding a good fit. Similarly, staff from CU's Educational Resource Center has introduced the idea of mind-maps (Buzan 1995; Buzan & Buzan, 2006) as a tool for students to use for decision-making and research projects.

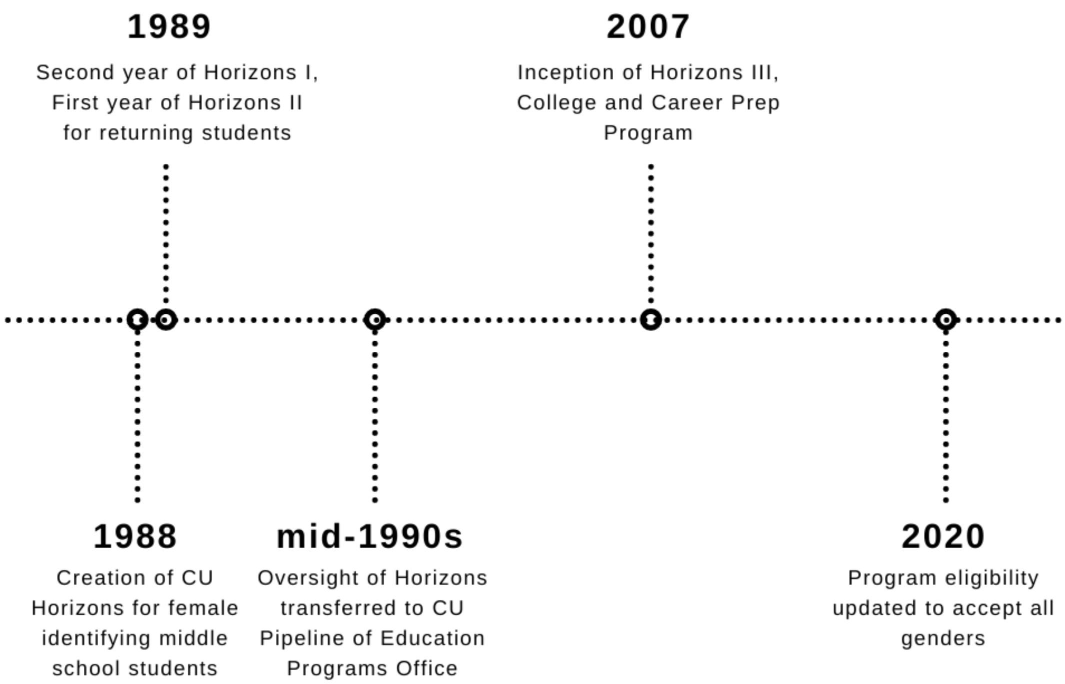
Campus visits are an integral part of overcoming the isolation of the region. In particular, there are few opportunities for teachers to spend valuable networking time with other educators in their disciplines, and campus visits facilitate those much needed interactions. Student participants have expressed that the campus visits are their favorite activity. Interaction with college students and exposure to the labs and facilities on campus sparks conversations about their future plans. Moreover, they meet students from across three counties, and with the program's strong retention rate, new friendships are formed. Students in this cohort often suffer hardships that lead to a range of emotional and mental health issues. These social gatherings can offer some relief, as food and prizes are provided at each event.

The program culminates with a week-long summer day camp focused on engineering and motivated by designing roller coasters (Wick, et al 2011, Fowler & Turner, 2010). Using a project-based learning approach, students form “roller coaster design companies” with three divisions corresponding to the grade levels: “Concept Engineers” (grades 7-8); “Design Engineers” (grades 9 - 10); and “Safety Engineers” (grades 11 - 12). Teachers act as company CEOs. Students learn the underlying grade-specific STEM content to design a roller coaster. A roller coaster card deck was developed to assist student companies with the design process that incorporates a series of linkable track segments. Only certain card combinations result in a feasible roller coaster. Concept Engineers act as the initial roller coaster architects, developing the preliminary design, including a scaled blueprint and a wire model. Those plans are passed to the Design Engineers who alter the original segments to ensure the coaster has enough energy to complete the ride. Safety Engineers then check the g-forces exerted on riders as they enter and exit turns, loops, and inversions to ensure safety. The final design is programmed within a simulation software package, where it can be “ridden” from a first-person perspective so students get to virtually experience their coaster in CU’s Motion Simulator Laboratory. A trip to Six Flags® theme park allows students to collect sound-level, temperature, altimeter, accelerometer, and heart rate data on real roller coasters and other park rides for analysis. Parents and school building leaders are invited to a final showcase where students present posters about what they learned.

Horizons is a long-standing residential summer program that engages CU faculty and students to work with middle and high school students, the majority of whom are from underserved populations in STEM, in a tiered mentor system to (a) build self-esteem to perform and apply their skills so they can envision themselves in STEM-based field of study and careers; (b) build confidence through interactive, hands-on, cooperative learning experiences in which participants work together to solve problems; and (c) promote self-awareness, leadership, and team-building skills. The program was created in 1988 to provide outreach to female middle school students in the local region who had an aptitude and interest in math and science (Williams, 1990). Any young women who participated in the first year (Horizons I) were invited to attend the second year (Horizons II) of the program. In the mid-1990s, Horizons moved to the Pipeline of Education Programs Office (now the Diversity, Equity & Inclusion Office), in part because of similar youth programming efforts in that office, most notably a 10-week residential research experience that was supported by the National Institute of Health (NIH). Under new leadership Horizons quickly expanded its reach – eventually inviting participants from over 400 middle schools, many of whom returned for Horizons II. Due to the growth and positive impacts of Horizons I and II, Horizons III was implemented in 2007 to provide a third-year continuation opportunity. Originally created to serve young women, Horizons began accepting all genders in 2020 although it still primarily attracts female-identifying students. Horizons is currently operated by faculty in the Institute for STEM Education, with outreach to over 115 different school districts from 40 counties throughout NYS. Three programs run concurrently to serve over 250 participants per year. Horizons I is a mathematics- and science-based outreach program for students in grades 6 through 8. Horizons II, for students in grades 7 through 9, is based on mathematics and engineering. Horizons III is the third-year program for students in grades 9 through 11 and focuses on helping participants explore college and career preparation, with the aim of preparing them to enter programs well-equipped for success. As a further incentive, CU provides annual scholarships to CU undergraduate students for every year they attend Horizons. Figure 3 illustrates the timeline of the evolution of CU’s Horizons Program.

Figure 3

Clarkson University Horizons Program Timeline



Over the years, school districts and the university have demonstrated value and commitment to ensuring Horizon's success. School administrators, counselors, and teachers are primarily responsible for program recruitment. Throughout CU, multiple departments and offices are vital to this effort, including the Diversity, Equity & Inclusion Office, Student Success, Marketing, Admissions, the School of Engineering, the School of Arts and Sciences, Office of Information Technology, and Campus Safety and Security. One faculty member's teaching load is assigned to administer the program within the Institute for STEM Education. These efforts have bolstered a widespread reputation for the Horizons program. They have leveraged lasting impacts through increased involvement of local teachers and student helpers and, more importantly, by preparing underrepresented students to enter STEM fields. A major outcome of the Horizon's program is that upon completion, participants will be able to make more informed choices when selecting high school courses and extracurricular activities that will lead to better preparation for college studies in these or similar fields. Since its inception, many of the participants in the series of Horizons programs have pursued undergraduate and graduate studies in STEM. Specifically, at CU, the Horizons program has been responsible for directing young women to attend CU in many STEM fields.

Engaging Undergraduate and Graduate Students as STEM Educators

The involvement of university students as educators and mentors is integral to most of CU's K-12 outreach programs. Knowing that students from high-need areas benefit most from mentoring (DuBois et al., 2002), ensuring that the rural K-12 students interact with college students is essential for increasing the K-12 students' cultural capital, or the social knowledge and behaviors developed through mentoring relationships (Philip & Hendry, 2000). In addition, peer networks are beneficial in influencing rural students' interest in attending college (Chenoweth & Galliher, 2004). This section highlights some activities where college students play a significant role in achieving program outcomes.

CU's Food-to-Energy Project partners CU faculty and students with teachers and students at Canton Central School in a place-based learning experience focused on food waste issues and resource recovery (DeWaters & Grimberg 2021, 2022; Clarkson Food-to-Energy, 2022). The program integrates a school-wide food waste recovery system with curricular and extracurricular lessons in food systems, waste management, and resource recovery and incorporates mentoring to a great extent. Since 2018, CU has worked with teachers and students to organize and operate a food waste collection system in their school cafeteria, whereby students separate their food waste into collection bins at the cafeteria waste stations. A team of CU students advises and supports the middle school Green Team and high school Environmental Club to organize the cafeteria food waste collection system. CU students deliver the food waste to a nearby learning farm that is part of Cornell Cooperative Extension Service of St. Lawrence County (CCE), an educational outreach facility focused on food and agricultural systems. CU researchers have operated a demonstration-scale anaerobic digester at the CCE Farm since 2010; the school's food waste is added to the anaerobic digester feed, producing biogas to heat a greenhouse on the farm, animal bedding from the recovered solids, and fertilizer. Since the program started in 2018, approximately 16 metric tons of food waste has been diverted to the anaerobic digester, producing about 3,400 m3 of biogas and saving the school district approximately $4000 in waste hauling fees.

The cafeteria food waste program offers an excellent opportunity for students to engage in place-based learning experiences that use the school as a living laboratory. CU students enroll in a credit-bearing project course. Mentored by CU faculty, students work in teams to develop and teach interactive, hands-on educational modules, so K-12 students learn the motivation for their cafeteria food waste program and the science behind anaerobic digestion. The CU students work alongside teachers in classrooms and after-school programs, serving the role of teacher/mentor. The project course consistently attracts a team of six to nine undergraduate STEM students, with several returning to the course a second or third time and many taking an interest in teaching. At least one student has been accepted to CU's MAT program because of the experience. The lessons they have developed cover a wide range of topics, from educational games about the food system to constructing mini compost cups and observing the biodegradation of food. Several are aligned with NYS Learning Standards. Each year CU students regularly work with the Canton middle school Green Team, an energetic group of about 15 fifth and sixth graders, and recently a second rural middle school has joined the partnership for an 8-week-long after school program that engages 10-12 youth of the same age. Two high school teachers have integrated a biogas experiment into their curriculum, which is tailored to specific course learning objectives (Burdick et al., 2021, 2022). For example, environmental science classes estimate the biogas produced from a typical dairy farm and the resulting impact on electricity-related CO2 emissions, and chemistry classes learn stoichiometry and biogas potential for digesting various types of food waste. Field trips round out the experience. Students visit the CCE farm and come to CU's campus to tour various sustainability initiatives, including the campus food digester, wind turbine, and LEED-certified buildings. In addition to the value of exposing students to the university, visiting with members of the CU food-to-energy team away from school provides another opportunity for mentoring on a different level. The Food-to-Energy project demonstrates how K-12 educational activities can be developed from university research projects, providing another avenue for university–community connections. The model can be applied to a range of research topics that are relevant to K-12 education. Curricular materials used in this program are available online (Clarkson University, 2022).

Informal education is another opportunity for college students to act as STEM Educators. In fall 2020, the Institute for STEM Education launched a new program with the local North Country Children's Museum (NCCM). The curriculum fosters an engineering mindset by engaging participants in the design process (Cunningham, 2018). One 10-week class was offered to pre-K through third graders and another to fourth through seventh graders, both designed for the appropriate grade levels and meeting for about 45 minutes each week. The curriculum was entirely developed by two students (one undergraduate, one graduate) and was delivered by a team of undergraduate STEM students. Participants acted as toy engineers and were tasked to design and build interactive toys from cardboard (Adolph 2020; Heroman 2021). Activities included building a marble labyrinth, a marble wall-drop, moveable cardboard robot hands, stomp rockets, and using their imaginations to repurpose a large cardboard box. For each activity, students brainstormed, planned, drafted blueprints, and iterated through testing and improving their creations. Throughout, information about recycling was included and students were encouraged to reflect on their own household practices. Most important was that students at both levels were involved in engineering practices. Throughout the class, students considered constraints and trade-offs in their designs. They were naturally challenged to persist, problem solve, and consider multiple options for their creation to be effective. Students made authentic choices and communicated to the group about their final products.

This endeavor will become part of an undergraduate class on Community Engagement, which focuses on methodologies from multiple fields and from diverse perspectives to help students develop an understanding of the social impacts of engagement through community-based service partnerships. In fall 2022, about 65 students will take the course, supported by the CU Honors Program. After studying the historical and cultural contexts of engagement and service, students will explore a range of relevant issues, including university–community relationships, cross-cultural encounters, interpersonal conflict and consensus, power structures, the concept of privilege, and the meaning of equitable community partnerships and outreach. Students will read case studies and immerse themselves in direct service. The NCCM will be one of the community-based service partnerships that allow students to explore issues surrounding childhood STEM education, educational access, and exposure to STEM.

Recruiting college students to engage in outreach can be challenging; identifying interested students, likely based on their own early experiences, is essential. The Living Learning Communities (LLC) offer first-year college students with similar interests the opportunity to live together and participate in programs that cater to their academic, social, and personal needs. In a study with first- and second-year students, Hurtado et al. (2020) found that LLCs have a positive influence on “collaborative learning, reflective and integrative learning, perceptions of a positive campus environment, perceived learning gains, and student–faculty interaction” (p.15).

CU offers numerous LLCs, some focused on hobbies and others more academically aligned with majors. A FIRST (For Inspiration and Recognition of Science and Technology) Robotics LLC was established in 2009 to engage both first- and second-year students who are interested in robotics and want to give back through service to community programs. This robotics-oriented LLC builds students’ 21st century professional skills (Bellanca & Brandt, 2010) through their participation in hands-on activities and local K-12 mentorship and by assisting with the annual regional FIRST competitions. More broadly, in 2019, CU established a STEM Ed LLC, designed for students interested in supporting the local North Country communities through mentoring and teaching. Opportunities are provided for CU students to work with local K-12 students and teachers through a wide range of STEM enrichment activities, which are discussed in this paper. CU students regularly help faculty run hands-on workshops and camps for local students throughout the year, provide after-school tutoring, and coach students in engineering challenges. These STEM-focused LLCs recruit students in their first year, and while some are relatively new, many continue to volunteer and engage in K-12 outreach activities in subsequent years.

Competitions and Challenges

Design challenges are a popular mechanism to engage and excite students in STEM studies and careers (David & Willenbrock, 1988; Elizondo et al., 2010; Kulturel-Konak, 2021; Mejia et al., 2019; Mentzer, 2011; Sadler et al., 2000; Van Haneghan et al., 2015; Zogaj et al., 2012). These programs provide authentic learning experiences that integrate STEM disciplines as participants work mostly in teams to solve real-world problems. Competitions can vary broadly – ranging from the traditional design-and-build model to IT and programming (e.g., ‘hackathons’ [Kulturel-Konak, 2021]) and even include ideas competitions for developing new procedures, strategies, or even small businesses (Zogaz et al., 2012). Design challenges have improved student engagement and motivation, feelings of self-efficacy, and concept retention (Mentzer, 2011; Lesseig et al., 2016; Mejia et al., 2019). They also allow students to develop important 21st century professional skills (Bellanca & Brandt, 2010) that will prepare them for today’s STEM careers, such as collaboration, communication, responsibility/accountability, decision-making, inquiry, and creative problem-solving. Additionally, competitions that expose the ‘human side’ of STEM, by emphasizing the social and ethical implications of STEM and the potential for creating societal good, appeal particularly to females and other underrepresented minority groups, providing an important avenue for engaging and supporting a more diverse group of students (Busch-Vishniac & Jarosz 2004; Godwin & Potyin, 2015; Kilgore et al., 2007).

The Institute for STEM Education supports a variety of STEM-related competitions and challenges that engage students at various levels, pre-college through graduate school, only a few of which are included in Figure 1. Several competitions are embedded in other programs; for example, CU-STEP also runs Game-on (a video game design challenge), No Limits (a roller coaster simulation challenge), POW (a STEM problem of the week challenge), and model roller coaster design challenge based on the national competition American Association of Physics Teachers. A few programs are described below that strongly support the rural K-12 partners shown in Figure 1: STEM QuESTS Challenge, Clarkson Discovery Challenge (CDC), CDC-

Space, and FIRST Robotics. FIRST and CDC-Space are based on national competitions, while CDC and STEM QuESTS were created by faculty at CU.

STEM QuESTS Challenge (Questions that Explore STEM for Teachers and Students) offers an alternative to the design and build, IT, or innovative product endpoint at the heart of most design challenges. Developed in 2021, the challenge invites CU students to create engaging STEM curricula to entice pre-college students to pursue STEM studies and careers. Students are asked to ‘think back to before college’ and consider what inspired them to choose their major and career pathway and then use that inspiration to create an educational experience, which could be a lesson, a set of lessons, or a module that could be incorporated into a middle or high school classroom. The lesson(s) should be unique and innovative, hands-on, interdisciplinary, or cross-disciplinary, and engage students in inquiry and active learning. Teams pitch their ideas in a 90-second Flipgrid video. The videos are used to evaluate entries and select four finalist teams. Each finalist team is assigned a mentor, an in-service or pre-service STEM teacher, or faculty from CU’s STEM Institute, to assist them with seeing their projects through to fruition. Students and mentors work together to develop their ideas into workable lesson plans tied to the NYS education standards. Final lesson plans, supporting resources, and recorded presentations geared toward teachers who might use their materials are submitted for evaluation and formal presentation to an audience composed of judges and members of the campus community and the general public.

Since its inception, the STEM QuESTS Challenge has engaged 48 undergraduate and graduate students from a range of STEM disciplines, including mathematics, chemistry, physics, computer science, and various engineering disciplines. Overall, the male-to-female gender ratio was approximately 50%, far higher than the percentage of females university-wide, 30%. Lessons touched on a wide range of topics, as shown by the examples in Table 1. All submissions have been very high quality. One of the 2021 judges, a science teacher from a local school district, commented about the four finalist entries: “I would use any of these in my classroom.” Several 2021 lessons have been used as part of class curricula or in after-school programs, such as CU-STEP described above. Student learning outcomes have been assessed for the Food-to-Energy lessons with simple pre-/post- and post-only online surveys. Among the 26 NYSED participants who responded to a simple post-survey, 21 students fully or partially saw connections between the lessons and things they learned in the classroom.

Clarkson University FIRST (For Inspiration and Recognition of Science and Technology) Robotics Outreach was established in the late 1990’s to provide local educators and students interested in robotics with professional development and an outlet to showcase their skills through friendly and collaborative competition. FIRST is a global robotics community, engaging PK-12 (ages 4-18) students in exciting, mentor-based research and robotics programs (www.firstinspires.org). There are three program levels within FIRST: FIRST LEGO League (FLL) for grades PK-8, FIRST Tech Challenge (FTC) for grades 7-12, and FIRST Robotics Competition (FRC) for grades 9-12. As a result of CU FIRST programs’ success, two regional FIRST competitions annually are hosted at the CU campus. Winners of these events advance to compete nationally in the FIRST Championship. Additionally, CU sponsors one FLL Explore Showcase hosted annually at a local school district. Table 2 illustrates each FIRST program and targeted grade level.

Table 1

Sample STEM QuESTS Entries, 2021 & 2022

Lesson	Description
The Mathematics of Cancer	Various lessons that apply mathematics concepts and modeling to cancer research tumor growth
Ice Cream Chemistry	Students focus on the science and chemistry of ice cream making, integrating many STEM concepts
Food-to-Energy	A problem-solving module with lessons focusing on recovering resources from food waste
Whiteface Mountain Earth Science	Virtual field trip to Whiteface Atmospheric Science Research Center, accompanied with various hands-on STEM lessons
Positive Altitude - Mechanics of Flight	Students build model airplanes and learn mechanics of flight.
Pathfinders - All about Light	Students experiment with prisms to learn about the light spectrum.
Aquaponics	Students construct and operate an aquaponics system. They learn symbiosis between plants and fish, system management, and sustainability.
Physical Block Based Coding	Students create physical puzzle-like block pieces connected to simulate coding.

Table 2

FIRST (For Inspiration and Recognition of Science and Technology) Robotics Programs supported by Clarkson University

FIRST Program	***Grade Level***	***Supported within CU Robotics Outreach***
FIRST LEGO League Discover	PK - 1	
FIRST LEGO League Explore	2 - 4	X
FIRST LEGO League Challenge	4 - 8	X
FIRST Tech Challenge	7 - 12	X
FIRST Robotics Competition	9 - 12	X

Institutional commitment to the FIRST Robotics program runs deep. The initiative is supported by a network of volunteers, educators, CU faculty/staff/students, and sponsors, who mentor teams using the FIRST Core Values (Discovery, Innovation, Impact, Inclusion, Teamwork, and Fun) to conduct research, design, build, test, improve, and present their solutions. Currently housed within the Institute for STEM Education, one faculty member's teaching load is assigned to administering the CU FIRST Robotic Outreach program. One outcome of this partnership was the creation of regional FIRST teams that have grown from supporting two school districts, which represented one FRC team, to supporting over 20 school districts consisting of 80 plus teams. CU also provides scholarships to high school seniors involved in FIRST.

Clarkson Discovery Challenge (CDC) is part of the programming associated with CU-STEP described above but shared here for its unique contributions to providing an authentic STEM Challenge experience. CDC participants select a research topic and work with CU students and faculty to collect data, test their hypotheses, and present a poster at an annual local showcase. The top teams from the local competition compete in a statewide student conference annually with other STEP programs from across NYS. Winning a spot at the Statewide Student Conference is a milestone for the program. All participants in CU-STEP struggle with poverty. To this end, the conference is an unforgettable experience for students, many of whom rarely, if ever, leave Northern NYS. Roughly 500 students from across the state come together in Albany, the capital of NYS, and are immersed in a completely different setting compared to their rural home region. The conference is student-focused with workshops on academic success, self-care, college preparation, and STEM enrichment. Social events include a dance party and banquet with a motivational speaker focused on successful STEM pathways. Clarkson's CU-STEP students have won multiple trophies over the years for their research projects.

At the heart of CDC is student engagement in authentic research, and all participants benefit regardless of going to the conference. CDC typically kicks off in September, but brainstorming and research activities take place year-round. Students learn about the scientific method and participate in an immersive workshop that provides an example of how research is conducted. Students work with their teacher coaches and CU graduate student fellows to choose a topic and design their research methodology. Over the course of several months, students carry out their research. They eventually draft a formal abstract and design their poster. A detailed rubric helps guide them and prepares them for answering questions that may be asked during judging. The CDC experience builds a range of transferable skills including data literacy, technical communication (oral and written), collaboration, interdisciplinary problem solving, and most importantly self-confidence.

Clarkson Discovery Challenge – Space (CDC-Space) is an extension of CDC that focuses on microgravity. This new (one-year old) project uniquely combines aspects of competition and outreach with the K-12 rural school community, with teams competing to send their experiment to the International Space Station (ISS). CDC-Space is part of a national competition, organized through the Student Spaceflight Experiments Program (SSEP), which is part of the National Center for Earth and Space Science Education in the U.S., and the Arthur C. Clarke Institute for Space Education internationally. The competition is enabled through a strategic partnership with Nanoracks, LLC, which is working with the National Aeronautics and Space Association (NASA) under a Space Act Agreement as part of the utilization of the International Space Station (ISS) as a national laboratory.

In this first DC-Space competition, 200 middle and high school students from rural school districts learned about microgravity. Through support from CU faculty and students, all students created their own experiments to test the effects of microgravity both on earth and in space. They learned about experimental design and proposal writing through first-hand participation in a real-world project that was connected to the SSEP competition. While it was challenging for many students, they learned about the true nature of science through first-hand experience. For example, they learned that science is a process that is not always done in a neat, stepwise fashion. They also learned to work within constraints; their experiment was required to fit within a certain size tube and could only be manipulated by the astronauts for a limited time over a certain number of days. The winning team from this first year of the competition designed an experiment to test the impact of microgravity on specific algae in space, with identical experiments conducted here on earth (by students) and on the ISS (by astronauts). The student team is invited to attend the launch of the experiment in Cape Canaveral, FL, and also to present their findings at the Smithsonian National Air and Space Museum in Washington, DC. The high school science teacher who works with these rural students said:

> The students were able to explore their own research ideas and get the satisfaction that they can be real scientists through experiments. They were empowered to put their thoughts on paper and perform their own research. Who knew that microgravity was a thing and is important in our daily lives? The experience will be something they will never forget. Some are already thinking of their proposal ideas for next year.

All students who submitted proposals and participated in the competition engaged in scientific work. They all experienced the amount of writing involved and the challenges of working within a set of tight constraints. Despite the challenging nature of the project, many students were engaged, felt competitive, and worked hard, hoping their proposal would be selected. CU faculty members helped as expert consultants to ensure the science was accurate. Students came to campus twice and completed the rest of the work virtually. This combination of in-person and virtual work is useful for supporting rural schools, where distances between school districts and the university, and among the school districts themselves, is often a challenge. The large geographic areas served by rural school districts contribute to transportation difficulties. The bus rides are longer, students return home late, and there are fewer transportation modes. However, the more recent experience of working online through the pandemic has supported students by enabling them to work together without having to travel. This is another example of how the relationship between a university and a K-12 school system in a rural area can be enhanced with creative programming solutions.

University Programming/Commitment to Education

In 2019 CU was awarded a Noyce Grant for their Teacher Preparation Program from the National Science Foundation, with the goal of preparing high-achieving math and science students to work in high-need schools. The program initially intended to compare the preparation of pre-service teachers for rural versus urban schools; however, many scholars were choosing to work in rural areas. As a result, the partnership team is faced with a new question: is preparing rural teachers becoming a large part of the identity of this program? Through this work, CU has joined 14 other universities interested in understanding how to recruit and retain science and math teachers to work in rural schools.

CU students who are interested in becoming STEM teachers have many opportunities and support to visit classrooms and participate in field observations. The University is committed to supporting STEM Education, as shown through the recently established Institute for STEM Education as well as other efforts such as allowing STEM outreach to be considered as part of a faculty member's teaching load. These examples demonstrate the University's commitment to actionable support, without which the multiple partnership activities described here would not be sustainable.

Recommendations

This article shares experiences and puts forth ideas on how other universities, particularly STEM-focused rural universities, can partner with local school districts to enhance STEM teaching and learning opportunities. A major challenge in rural education involves inequitable opportunities in STEM. The partnerships described above are critical to deeper learning in STEM; at the same time, they directly broaden participation in STEM by engaging more students who are socioeconomically disadvantaged. These partnerships respond to national calls for improving and diversifying the STEM workforce by supporting and promoting programs that broaden participation and are shown to be effective.

Key to the success of these programs is a commitment from all stakeholders – university leadership, faculty, students, organizations, and offices as well as partnering school district leaders, teachers, students, and parents. Time and energy are the most valuable resources, but funding enables programs to grow and thrive. Of utmost importance is a commitment from leadership at the university and school district levels. If faculty believe that outreach is valued, for example towards tenure and promotion, they are more likely to engage more deeply in the development of large-scale activities. If school district leaders' input is valued, they feel buy-in. If teachers are supported for their time and efforts by building leaders, they will be willing to take risks and try new experiences in and outside of their classrooms. Support from university and school district leaders will ensure that programs are sustained from year to year. Below are some final thoughts for building community partnerships between a STEM university and rural school districts:

1. Seek out people on campus who are invested in building partnerships with the local community, in particular faculty and campus community members who are parents and understand the challenges on a personal level.
2. Establish a dedicated position at the University for someone (e.g., a retired school teacher, superintendent, building leader) who can help establish relationships with school districts, get buy-in, and assist with curriculum design so it is delivered at the appropriate level.
3. Persistently seek funding (e.g., the CU-STEP grant took three tries; the Noyce grant took two tries).
4. For developing programs or partnerships, start small to develop a proof of concept and then grow out ideas as you apply for funding – consider local agencies/industries, state programs, and national funds.

5. Learn about poverty and rural challenges – the local K-12 students are likely different from the ones you have in your college classrooms; learn and understand the local community.
6. Garner support from offices on campus – send out a campus-wide call for help; you may be surprised by who wants to get involved.
7. Advertise broadly for college student helpers--they often love to volunteer.
8. Showcase student engagement and teachers' commitments in local papers, news channels, social media, and events to spread the word of the important and impactful work you are doing – this can help get buy-in and support from both the school district and the families involved.

These recommendations are based on years of experience, mainly from a handful of faculty who helped create these networks and cultivated their relationships over the years. Like any geographic area, rurality has its own unique challenges. However, with strong institutional leadership, a sense of shared ownership and accountability, and culturally relevant programming, a university–community partnership can be established, broaden participation in STEM, and ultimately narrow the inequities that exist in rural communities.

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About the Authors

Katie Kavanagh, PhD, is the director of the Institute for STEM Education and a math professor at Clarkson University. Dr. Kavanagh's research interests include numerical analysis, computational mathematics, non-linear equations, and many applications of mathematics. She also has an extensive background in creating and teaching professional development for K-12 STEM teachers.

Jan DeWaters, PhD, is an associate professor in the Institute for STEM Education with a joint appointment in the School of Engineering at Clarkson University and teaches classes in both areas. Her research focuses on developing and assessing effective, inclusive teaching and learning in various settings. An environmental engineer by training, Dr. DeWaters's work typically integrates environmental topics such as energy and climate into STEM settings.

Seema Rivera, PhD, is an associate professor of science education at Clarkson University. Her research interests include STEM Teacher preparation and the intersection of diversity, equity, and inclusion with STEM both in K12 classrooms and higher education. She works with STEM preservice teachers and is the principal investigator for the Noyce Scholar program at Clarkson. Dr. Rivera is a former chemistry teacher.

Melissa Carole Richards, PhD, is an assistant professor and director of the Horizons Programs and Robotics Outreach Programs with the Institute for STEM Education at Clarkson University. She is committed to fostering greater diversity, equity, inclusion, and belonging in academia as a whole and engineering specifically. She holds an Associate of Science in Engineering Science from Nassau Community College. In addition, she earned a Bachelor of Science in Mechanical Engineering with a minor in mathematics and a Master of Science and Doctorate of Philosophy in echanical Engineering, all from Clarkson University. Her research interests are in theoretical rock mechanics and STEM education.

Mike Ramsdell, PhD, is an associate professor of physics at Clarkson University; his research interests include physics education research, laboratory curriculum development, and design. Dr. Ramsdell has focused on implementing and assessing the physics team design program for the calculus-based introductory Mechanics, Electricity, and Magnetism courses. Dr. Ramsdell also has an extensive background in developing and running STEM professional development and STEM camps for middle and high school students.

Ben Galluzzo, PhD, is an associate professor of mathematics at Clarkson University. Dr. Galluzzo's area of research concentrates on developing new strategies and best practices for bringing innovation and active learning into K-16 STEM classrooms, with a particular emphasis on mathematical modeling. Dr. Galluzzo also has an extensive background in creating and teaching professional development for K-12 STEM teachers.

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TPRE Editorial Board for Volume 12, Issue 2

Call for Manuscripts to *Theory & Practice in Rural Education*
http://tpre.ecu.edu

Schedule and submission dates

Spring 2023	January 15th	General topics
Fall 2023	March 27th	**Transformative Trauma-Informed Practices in Rural Schools**
Spring 2024	January 15th	General topics
Fall 2024	February 28th	Special issue **TBA**

The editors of the *Theory & Practice in Rural Education* would like to invite authors to submit manuscripts for forthcoming issues. *Theory & Practice in Rural Education* is a peer-reviewed journal published electronically twice per year, spring and fall. We are predominantly interested in manuscripts related to promising and effective educational practices in rural schools, educator preparation for rural P-16 institutions, and issues related to distinct rural populations. We invite several types of articles and/or multimedia creations, including those with an international focus: practice-based; educational innovations; partnerships for education; research-based articles; review articles; and book reviews focusing on rural education. (Please see Author Guidelines at the website for additional submission information.)

All proposals will be subject to double blind peer review.

Dr. Kristen Cuthrell, Director
Rural Education Institute, College of Education, East Carolina University
Mail Stop 122 (Building 123), Greenville, NC 27858-4353 | 252.328.5748

Theory & Practice in Rural Education (TPRE)

Call for Special Issue on
Transformative Trauma-Informed Practices in Rural Schools

Guest Editors

Loni Crumb, PhD (*East Carolina University, College of Education*)
Jennifer C. Matthews, PhD (*East Carolina University, College of Health & Human Performance*)
Dr. Taryne M. Mingo (*University of North Carolina at Charlotte*)

Transformative Trauma-Informed Practices in Rural Schools

Rural schools are key places for accessing children in need of supportive mental and behavioral healthcare services (Franklin, 2021). With appropriate supports and interventions that integrate trauma-informed principles, rural youth can overcome traumatic and adverse childhood experiences such as physical and emotional abuse, poverty, homelessness, substance abuse, exposure to household dysfunction, parental separation, and accidents and injuries (Center for Disease Control, 2021). The Substance Abuse and Mental Health Services Administration (SAMHSA) outlined six principles that guides a trauma-informed approach: 1) safety; 2) trustworthiness and transparency; 3) peer support; 4) collaboration and mutuality; 5) empowerment, voice, and choice; and 6) cultural historical and gender issues. Trauma-informed systems approaches rely on institutional environments to embrace and translate into practice value-driven approaches to student learning and services that leverage healing from adversity and minimize the risk of re-traumatization (Huang et al., 2014). For youth-serving rural institutions, this is especially important as childhood, adolescence, and emerging adulthood are sensitive developmental periods in which healing from adversity can occur (Cantor et al., 2018; Crumb et al., 2019). Furthermore, rural school personnel and other adults who work with students who have experienced trauma are at risk of burnout and compassion fatigue (Figley & Ludick, 2017; Mullen & Gutierrez, 2016).

A combination of school and community-based interventions may circumvent common mental health treatment barriers faced by rural students such as transportation difficulties, time constraints, communication break downs, knowledge gaps, and reduce the stigma associated with seeking mental health services (Franklin, 2021; Huang et al, 2014). School-based mental health services offer a viable pathway to provide trauma-informed programs and services to help build resiliency and decrease the mental, emotional, and academic distress associated with traumatic and adverse experiences. In this special issue of TPRE, we aim to highlight research, teaching, and professional practices that promote trauma-informed care in rural settings. Manuscripts selected for this special issue might address aspects of the following in relation to rural youth and communities:

- Understanding trauma in the context of diverse rural communities
- Leveraging school-university-community collaborations to support rural students' mental health and wellbeing
- Strength or asset-based frameworks that support trauma-informed principles and empower rural students
- Implementing policies related to trauma-informed care
- Innovative practices in teaching and/or learning that support a trauma-informed approach
- Trauma-informed educator and/or counselor preparation
- Advantages, challenges, and/or opportunities regarding trauma-informed practices in rural schools and communities
- Community-based initiatives related to the mental and behavioral health of rural students and school personnel
- On-site or telehealth practices to address trauma experiences and the mental health of rural students and school personnel

This work could explore classroom or school practices, educational leadership, librarianship, counseling, or other specialist work in P-20 educational and/or community and clinical settings.

Those interested in being considered for this special issue should submit a full manuscript to the TPRE system (http://tpre.ecu.edu) by **March 27, 2023.** Questions about possible topics or ideas should be sent to Dr. Loni Crumb (CrumbL15@ecu.edu). All submissions will go through the TPRE process of double-blind review by experts in the field. TPRE Author Guidelines: http://tpre.ecu.edu/index.php/tpre/about/submissions#authorGuidelines

Estimated Timeline

- Manuscripts Due March 27, 2023
  - o Accepted on a rolling basis up until the close date
- Double Blind Review Process:
  - o Approximately two-month turnaround (April/May)
- Articles selected for Revise/Resubmit or Minor Edits
  - o Revise/Resubmit Deadline: 45 days from receipt of feedback (May/June)
- Second (limited) Double Blind Peer Review Process from resubmissions:
  - o Approximately one-month turnaround (July)
- Final selection of articles selected for Minor Edits
  - o Deadline: one month from receipt of feedback (September)
- Expected Publication Date: October 2023

Dr. Kristen Cuthrell, Director
Rural Education Institute, College of Education, East Carolina University
Mail Stop 122 (Building 123), Greenville, NC 27858-4353 | 252.328.5748

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Dr. Kristen Cuthrell, Director
Rural Education Institute, College of Education, East Carolina University
Mail Stop 122 (Building 123), Greenville, NC 27858-4353 | 252.328.5748