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Sustaining Engineering Education for Rural Contexts: Implications from a Multi-year Study

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We studied how three rural teachers continued to apply locally relevant engineering practices after a five-year nationally funded project ended, despite lacking formal support. Our research aimed to identify key factors that either aided or hindered the ongoing use of these practices in their classrooms. While the initial adoption of the practices was successful, sustaining them without formal support proved challenging. Our findings highlight that administrative support, teacher agency, and resource availability were essential factors. Furthermore, the specific rural contexts of each teacher presented unique obstacles to maintaining the benefits gained during the project. We conclude that achieving sustainable change in engineering teaching practices requires a collaborative approach that considers the differences across school and classroom environments.
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***Keywords*: rural, STEM education, professional development, locally relevant engineering education practices**

Rural communities hold many assets that can enhance STEM learning. Children come into the classroom with a wealth of knowledge accumulated from their day-to-day lives. These funds of knowledge, or FoK (Moll et al., 1992), develop through activities such as outdoor exploration, tinkering on farm equipment, and building forts, and FoK can have direct parallels with science and engineering concepts taught in the classroom (Avery & Kassam, 2011). Leveraging these funds of knowledge and connecting classroom learning to local contexts can increase academic success, while simultaneously contributing to community vitality (Sobel, 2004) and support STEM course perseverance (Sprowls et al., 2019). Despite the positive outcomes of connecting STEM instruction to local contexts, students will only have access to these types of learning experiences if their teachers know how to develop and implement them. To support effective STEM instruction, K-12 teachers must be provided with professional development on how to connect STEM instructional materials to local contexts (NASEM, 2024). Numerous efforts exist to provide high-quality STEM-focused professional development (PD) to teachers, yet little is known about the long-term effects of these PD efforts on their teaching practices (Shume et al., 2022; Kennedy, 2016). Further, even less is known about the effects of these efforts on rural STEM teachers.

Research highlights that achieving lasting changes in teaching practices is a significant challenge in education (Coburn et al., 2012). Studies show that changes made by teachers toward specific practices through PD programs or policy requirements often diminish over time, or teachers revert to their old practice once external funding and support are withdrawn (Hubers, 2020). Furthermore, as suggested by Drits-Esser et al. (2017), many PD programs intended to facilitate necessary changes in teacher practices often lack funding for prolonged engagement, “putting into question the sustainability of the teacher learning that occurs during the course of the program” (p. 377). These issues highlight a significant problem in sustaining the impact of innovations or well-intended changes on teacher behaviors, classroom practices, and student learning (El-Hamamsy et al., 2024).

The literature also indicates that new practices or innovations are generally examined in the initial stages of implementation, with less follow-up on how these changes are sustained over time (Howard et al., 2021; Sandholtz & Ringstaff, 2016). This is especially true for local changes or those resulting from PD programs. While many studies investigate how nationwide, statewide, or even organizational policies and changes are implemented (e.g., Rigby et al., 2016), the literature does not offer much on the long-term effects of PD programs despite the increasing demand to understand what happens after a PD program or when funding for PD programs is withdrawn (Hubers, 2020). Teacher educators need to understand the trajectories of teacher changes or how and why changes are or are not sustained over time to better design and deliver professional development opportunities that have long-lasting positive effects on teachers' practice

A limited number of studies list contextual factors involved in sustaining changes in teacher practices. For example, Sandholtz and Ringstaff (2016) found that contextual elements affecting changes in teachers' inquiry-based science instruction following PD include support from administration, support from colleagues, and available resources. Rural teachers often face professional isolation due to low school populations and large geographic distances between schools (NASEM, 2024) which can limit the follow up support from colleagues described by Sandholtz and Ringstaff (2016). Additional studies are needed to examine how teachers implement and sustain practices, in particular in relation to the subjects that have only recently entered the spheres of elementary schooling, such as engineering or computer science. Understanding how changes are sustained in rural districts where teachers already face a lack of support in introducing these subject areas into their elementary classrooms or lack extended PD opportunities in these areas, is especially warranted (Inouye et al., 2024).

Therefore, in this paper, we investigate the perspectives of three rural teachers on what enables sustaining locally relevant engineering practices after the conclusion of a five-year nationally funded project in the absence of formal support. In particular, we explore the following research question:

> *What elements do rural teachers identify as significant for the sustainability of engineering practices in elementary classrooms after the conclusion of a five-year nationally funded project?*

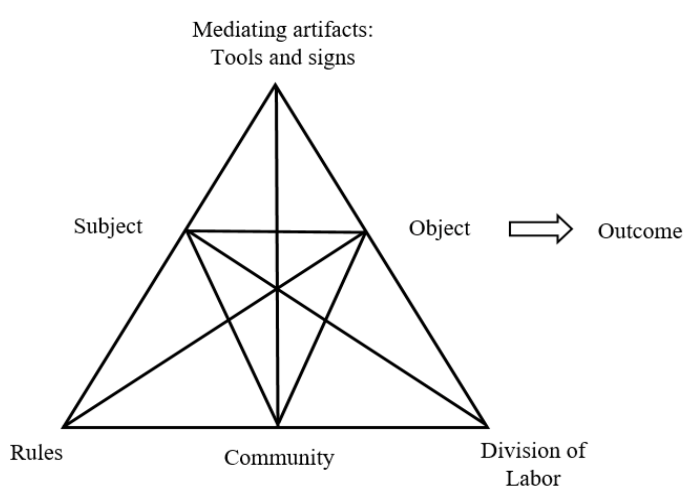
Theoretical Framework: Cultural Historical Activity Theory

Cultural Historical Activity Theory (CHAT) aims to understand human actions and behaviors in their social and cultural contexts. Originally developed by Vygotsky (1978), CHAT provides a robust theoretical framework that emphasizes the role of *mediation* in human actions. According to Vygotsky, individuals internalize cultural tools and signs to interact with their environment and each other. These tools and signs, or mediating artifacts as Vygotsky called them, can be intangible tools such as language or cognitive processes (memory and attention) or technical tools that include physical objects used to manipulate the environment. Vygotsky posited that these tools do more than extend human capabilities—they transform the psychological processes they mediate. When children learn to write, for instance, it is not merely the act of learning to form letters on a page; it is the internalization of a cultural practice that shapes how they think, plan, and even remember information. Vygotsky's student, Leointiev (1982), built on Vygotsky's concept of mediating tools and signs or artifacts and claimed that mediation is *collective* in nature, and "the activity of the human individual is a system that obeys the system of relations of society. Outside these relations human activity does not exist" (p. 397). Leontiev (1982) argued human activities are object-oriented (see Figure 1). *Object* in CHAT means "the true motive" which gives meaning to individuals' actions as embedded in social and cultural practices (Leontiev, 1978; Kaptelinin, 2005). Cole and The Distributed Literacy Consortium (2006) described this process as,

> Educational activities and cultural practices need to be conceptualized as social systems with several elements: the interplay among persons as active subjects, their competing or complementary objectives, the tools (mediational artifacts) they deploy; the social rules they formulate and debate, the communities they formulate and inhabit, and the divisions of labor that govern the configurations of their joint actions. (p. 15)

Figure 1

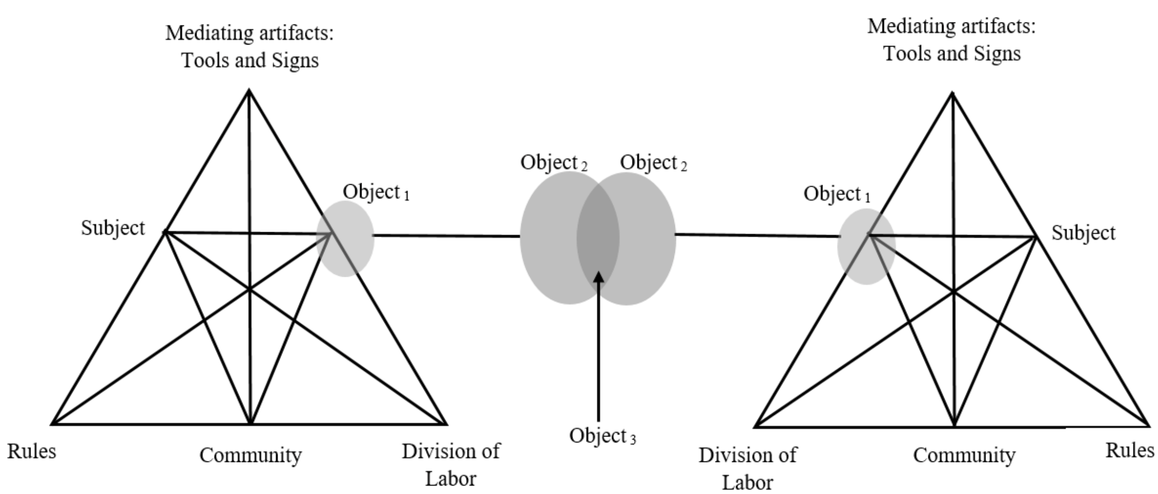
Triangle of Activity



Elaborating on Leontiev’s model, Engeström emphasized individuals and collectves’ change within activity systems (Engeström, 1999; Roth & Lee, 2007). Engeström developed what is now referred to as third-generation Activity Theory and visualized this expanded theory using a model of interacting activity systems. In this expanded theory, multiple systems–such as teachers, students, administrators, policymakers–simultaneously shape and reshape each other through their interactions (Figure 2). This approach highlights the interconnectedness of different groups or communities, each with their own tools, rules, and divisions of labor. Furthermore, Engeström's model is particularly insightful because it incorporates the concept of contradictions as central drivers of change within and between activity systems (Engeström, 1999, 2001). Engeström suggests that these contradictions—misalignments or conflicts between different components of an activity system (such as between the tools used and the norms governing their use) or between different activity systems—can serve as catalysts for change.

Figure 2

Interacting Activity Systems (Engeström, 2001, p. 136) (permission obtained)



The recent literature shows that CHAT helps understand how new knowledge or pedagogies in STEM are integrated into the rural teachers’ existing “activity system” of teaching (Boz & Allexshat-Snider, 2024; Mendenhall et al., 2022) and how rural schools leverage local resources and traditions as assets for curriculum (Moreno, 2022). In this paper, we used CHAT to understand activity systems that mediate or conflict with the sustainability of locally relevant engineering education in rural contexts. CHAT is particularly useful to analyze complex social phenomena. The application of CHAT allowed us to capture the interacting and evolving activity systems involved in sustaining locally relevant engineering in rural settings. Furthermore, we employed CHAT to identify tensions and contradictions within activity systems that may hinder the full utilization of rural teachers' and students' assets, as well as to understand how these assets serve as powerful mediating elements in sustaining engineering education in rural contexts. Finally, we discussed possible interventions that would align with the needs and realities of rural schools in teaching and expanding their engineering education practices.

Methods

We used a single case study design (Yin, 2018). The case focused on the sustainability of using locally relevant engineering practices in rural elementary classrooms which was the goal of a multi-year federally funded project that took place in the US mountain west. The case study draws on the experiences of three rural elementary teachers who were engaged in the project.

Yin (2018) views a case study as an empirical approach focused on a contemporary phenomenon known as the "case." It acknowledges the real-life context, particularly when the boundaries between the "case" and its context are not clearly defined. The project aimed at increasing rural and Indigenous youths' awareness of engineering and engineering related careers, with the goal of developing their identities as engineering learners. We worked with rural elementary teachers for a period of four years to develop classroom engineering activities that connected to students' funds of knowledge (Moll et al., 1992). In the first year of the grant, we collaborated with elementary teachers to learn more about students' cultures and knowledge and introduced teachers to engineering design-based teaching (Hammack et al., 2021). We also provided a workshop on how to use microcomputing technology to support engineering instruction in the classroom and provided teachers with curriculum and materials to adapt for use in their classrooms. After participating teachers suggested that water use was a central issue each of their communities faced in agriculture operations in their contexts, teachers guided their students through the use of the microcomputers to design and build a self-monitoring water system for a garden. In the second and third years of the grant, we supported teachers in applying and refining the engineering lessons and instruction and developing additional lessons more precisely connected to their unique local contexts. We encouraged teachers to integrate local funds of knowledge in their lesson designs and identify specific community problems or needs to address through their locally relevant engineering lessons (Inouye et al., 2024; Dalvi et al., 2016; Tan et al., 2019). We provided teachers with financial support to purchase supplies as well as classroom implementation support by visiting their classrooms face to face and virtually during the first three years of the project; additional detail about classroom support is included in the next section. During the fourth year of the grant, the research team did not visit the classrooms but still provided financial support for teaching supplies needed to teach engineering lessons connected to the local context.

Participants

The participants in this study included three fourth and fifth grade elementary teachers working in different rural communities in the US mountain west. Each participant was provided a pseudonym (see Table 1). Courtney is a white female with more than 33 years of classroom teaching experience. During this study, she taught 5th grade at a rural school located on a Native American Reservation, approximately 60 miles from the small city where she lived. All students at the school were classified as low socioeconomic status. Access to clean water was a concern on the reservation due to drought as well as water pollution, and Courtney chose to focus her lesson on irrigation systems designed to conserve water, while meeting the water needs of the community’s citizens as well as plant and animal stock of local farms and ranches. Students worked through a number of activities including moving water from place to place by designing water irrigations systems using cups and straws. The research team visited Courtney’s classroom and taught the students how to use Micro:bit (a single board computer, for more information please see https://microbit.org/) and sensors to monitor water quality in soil. Later, the students used the sensors to build a model self-watering garden. Members of the research team also joined the class via zoom to help support students as they began using Micro:bits and sensors to build their model gardens. Taking what they learned from the model self-watering garden, students built a larger self-watering garden that they used to start seeds inside their classroom to later transplant into the school's garden. Finally, the students worked to design and install an irrigation system to water the school's garden to ensure the plants received the needed water requirements during weekends and when school was out for the summer.

Holly is a white female with 18 years of classroom teaching experience and taught 4th grade in a small town located approximately 10 miles from the large town where she lived. Approximately 30% of the students at the school were classified as low socioeconomic status. Holly's class focused on two locally relevant engineering design tasks. The first was related to wildfires. The students designed and built box fan air filters to deliver to the residents of a neighboring town who were experiencing unhealthy air quality due to a wildfire. Wildfire induced air quality was something the students had personally experienced recently when a fire was active on their mountain and they wanted to help the nearby community that was now experiencing a similar issue. The second was a building design plan that would help reduce the impacts of ice-jam related flooding along their local river. At the time of the lesson, the local river was experiencing an ice-jam flooding warning. Students spoke with a flood plan engineer and conducted simulations to learn about different remediation methods (e.g., levee, fill, stilts). Then, they were given maps of the river with building sites along the river and asked to propose a plan for how to use the building sites given their knowledge of different flood remediation methods. A member of the research team helped Courtney with delivery of both lessons, co-teaching approximately 75% of the lessons.

Jennifer is a white female with 10 years of classroom teaching experience and taught 5th grade in the same small town where she lived. Approximately 48% of the students at the school were classified as low socioeconomic status. Jennifer designed and implemented a lesson connected to the school's partnership with a local composting company as part of a farm to table program. The students learned that most of the compostable material collected from their cafeteria had to be thrown away because it was contaminated with non-compostable materials. They interviewed cafeteria workers, compost experts, administration, teachers, and students to gain a better understanding of the problem. Then, they developed a lunch room plan that included moving locations of trash and compost bins, specific lunch room routines for emptying trays, and a messaging campaign to inform the student body about composting. The research team worked with Jennifer during the initial planning of the lesson as well as visiting the classroom to support the students during their lunch room solution planning.

Table 1

Participant Background

Teachers	Years of Teaching Experience	School Context	Grade	Enrolment by Race and Ethnicity*
Courtney (White)	33	Reservation and rural, remote	5th Grade	97% Native American, 2% Hispanic, 1% more than one race
Holly (White)	18	Rural, fringe	4th Grade	87% White, 7% Hispanic, 6% more than one race, less than 1% Black
Jennifer (White)	10	Town, distant	5th Grade	91% White 4% Hispanic, 4% more than one race, less than 1% Native American, Asian

Note. *Information about demographics was retrieved from the National Center for Education Statistics (NCES). While Jennifer’s school was classified as Town, her community shared many characteristics with the rural, fringe school where Holly worked, and many of Jennifer’s students came from outlying ranching communities. As described by NASEM (2024), categorization systems such as NCES do not adequately capture the rural nature of some schools.

Data Collection and Analysis

For this study, we collected data from teachers through semi-structured interviews (individual and focus group interviews) at the conclusion of year four of the project after teachers had spent the academic year without direct support for the design and delivery of the locally-connected engineering lessons First, teachers participated in a focus group session with members of the research team to share their experiences teaching engineering during the prior academic year (grant year 4). The focus group session lasted approximately 90 minutes. Rural teachers are often professionally isolated and value time to interact with peers (Bowen et al., 2021; Gallagher & Woolard, 2022). Over the course of the project, we found this to be true for our participants as well, with rich conversations taking place about their teaching practices every time the teachers interacted with each other. For this reason, we chose to hold a group interview to explore participants' joint experiences as well as honor their desire to debrief with each other.

Within the two weeks after the group interview, each teacher participated in an individual interview during which they shared additional thoughts about their year and plans for teaching engineering in the future. The individual interviews allowed the research team to collect more in-depth data from our participating teachers. Individual interviews lasted between 35 and 45 minutes. During the interviews, we focused on the teachers' experiences of teaching engineering in their classrooms. Specifically, we wanted to identify if their approaches to teaching engineering had changed during year 4 when they did not receive in-classroom support from the research team when compared to previous years when the research team provided in-class support. We also wanted to learn about their future plans for teaching engineering now that the grant had ended and they would no longer receive financial or classroom implementation support. We asked questions about their current engineering teaching practices, the challenges they faced in sustaining their gains from the project, what helped them sustain—or not sustain—engineering education in their classrooms, and any strategies they employed to continue incorporating engineering into their curriculum.

All teacher interviews (individual and focus group) were transcribed for data analysis. We employed thematic analysis (Braun & Clarke, 2006) to uncover key mechanisms behind teachers' implementation of locally relevant engineering education.

In doing so, we used open coding (Strauss & Corbin, 1998) to identify recurring themes and patterns across the interviews. These codes included categories such as access to materials, administrative support or teacher agency. From these codes, we constructed broader themes aligned with key CHAT elements (in particular, tools, community, and rules) to trace elements that enabled or conflicted with teachers' efforts to sustain locally relevant engineering lessons in their classrooms. Our analysis moved iteratively between transcripts, codes, and key CHAT elements to ensure themes were grounded in participants' voices and experiences.

Researcher Positionalities in Relation to Rural Education

Our international research team consists of scholars with diverse backgrounds related to rural education, resulting in deep knowledge and expertise working with rural teachers. We each have more than a decade of experience living and working in rural areas, including the Northeast, Southeast, Southwest, Midwest, Intermountain West, and Appalachian regions of the United States. Further, multiple members of the research team are former rural K-12 teachers, and our team has more than 40 years of cumulative experience providing professional learning and instructional support to teachers in rural areas. We all view rural spaces and schools as assets filled, and value the professional expertise that rural teachers bring to our project and our understanding of sustainability in education. We acknowledge that our shared commitment to rural education may have influenced our data collection and analysis. To account for this, we held a two-hour structured reflection session as a research team to examine the overall successes and challenges encountered in sustaining engineering education in rural school contexts. This session provided opportunities for ongoing reflexive practices and helped guide data collection and analysis. Additionally, we center the voices of our participating teachers in this case study and ensure that data analysis and sense-making were grounded in participants' voices rather than our own expectations.

Findings

From the perspective of the Cultural Historical Activity Theory (CHAT), we approached the case of engineering education in rural elementary schools as an activity system where students, teachers, and communities interacted through mediations and contradictions (conflicts) that mediated or conflicted with teachers' actions of sustaining engineering in their classrooms.

Below we described the mediations teachers expressed in their teaching of engineering and contradictions (conflicts) in sustaining these practices in their classrooms.

Mediations

Student Engagement

All three teachers emphasized that engineering lessons offered hands-on and real world problem solving opportunities for their students, which in turn cultivated persistence, problem solving skills, and creativity in their students. Observing student enthusiasm in engineering classrooms and the role of engineering in developing students' soft skills (or essential life skills) drove teachers to advocate for and implement engineering-focused activities in their classes during and after the project.

For example, Jennifer indicated that engineering education in elementary classrooms is essential for fostering grit, persistence, and creative problem solving in students. She noticed that engineering activities engage all students with open-ended problems that require active, hands-on solutions. Jennifer explained:

> It's so good for them to have an open-ended question and they have to try and solve it. It's just like the teacher is not teaching. There's no right or wrong answer. You have to figure it out. And I just love to watch kids struggle through that.

Holly saw engineering education as a transformative tool for elementary students to engage actively in solving real-world problems and gaining a strong sense of identity as problem solvers. During the project, in her classroom she often discussed engineering concepts, and her classroom frequently hosted various engineers. She designed engineering lessons that addressed community needs. For example, as described above under participants, in a notable engineering lesson, her students addressed local wildfires by creating products to filter smoke and donated those to staff, families, and community members: "The kids just every time we do that, they're so excited that they're helping people." By engaging students in solving real, immediate problems, Holly fostered a sense of civic agency in students and encouraged them to use engineering along with local assets and knowledge to address community issues.

Courtney valued the creativity and problem-solving aspects of engineering education and her students' high engagement with engineering lessons:

> The kids relate to it so they have enthusiasm for it and just the way that they engage in the activities, it just makes it more enjoyable as a teacher. It makes the kids more engaged, more willing to do the work.

Figure 3

Pictures from Holly's (left) and Courtney's (right) Classrooms

Access to Funding and Materials for Engineering Integration

Access to continuous funding and materials that allowed the integration of engineering into other subject areas enabled Courtney and Jennifer to sustain engineering lessons in their classrooms. Courtney indicated that she did not have any issues accessing resources once the project finished, and she did not encounter difficulties in finding funding to purchase materials for teaching engineering in her classroom:

> I worked with the Air and Space Museum last summer and so then they gave me money for materials…So if you are willing to give up some time and make some effort, it's not too difficult to get some materials. Same with a lot of donors.

This excerpt exemplifies how Courtney leveraged community connections to access resources and how her proactive engagement with local networks and supports helped her sustain engineering integration. Furthermore, the support and the resources Jennifer received through the project such as literacy books helped her to integrate engineering into her English Language Arts classes. Courtney also indicated that she saw engineering education as integral to teaching a variety of subjects. Therefore, she was able to include engineering in various subject areas

> I was able to incorporate literacy into the science and math, into the science, social studies, into the science and find some, there's a reading series that uses a lot of the same ideas on engineering and water and they use a book called One Well and then really leads into the styrofoam cup activity that we do.

Contradictions

Declining Autonomy and Decreasing Emphasis on Science and Engineering

Jennifer and Holly emphasized that they experienced declining autonomy and decreasing emphasis on science and engineering in their school and district administration, which conflicted with their efforts to sustain engineering in their classrooms. For example, after the project concluded, Jennifer could not integrate engineering as much as she did during the project time. She listed declining teacher autonomy and decreasing emphasis on science in her school district and differing job expectations as primary obstacles: “We are getting to the point that teachers have lost enough autonomy of their day…We are really losing our individual discretion in the classroom.” She prioritized engineering and science lessons in her classroom; however, as the current school administration did not value these subjects, she struggled to teach engineering after the project ceased: “I know kids love it [engineering]. I know it's good for kids, and yet I can't justify taking the time away from the students in my classroom and those other content areas I'm expected to teach.”

Holly had support from her administration, and her school and district administration valued her engineering lessons; however, she believed that this support alone was not sufficient. Holly expressed her frustration with administrators who verbally approve initiatives like engineering without tangible support, such as professional development or allocated time within the school day. Furthermore, Holly highlighted challenges with the rigid scheduling enforced by her district, which introduced new programs that heavily structured classroom time, leaving little flexibility for integrating engineering or other initiatives into her classroom: "Our district purchased programs, new programs, and unfortunately, it has gotten very regimented in our schedule. This is your math time; this is intervention time. This is ELA."

Limited Resources and Materials

Once the project ceased, Holly had challenges implementing as many engineering lessons as she had in the previous years. She needed support to come up with engineering lessons that would target community issues that are changing. She noted:

> There's not a bank of resources that you can find because you have to know the community and it's always changing. And so, I think that those things for teachers… It's just difficult. And the resources, I know in my district, they're supportive of it, but they don't provide us any resources to do it either.

Limited access to some resources and materials was another obstacle Jennifer identified for teaching engineering this year. Ready-to-go engineering kits that would target school or community-specific problems and needs were among the resources Jennifer wished she had more access to. Jennifer's experiences also highlight the importance of treating the community as a living curriculum—one that offers evolving local problems and knowledge systems for students to engage with in engineering lessons.

Community Issues

Courtney noted that her students were well aware of community issues, which helped them develop targeted engineering projects to address these concerns effectively. However, sustaining community-focused engineering practices in her classroom posed challenges due to her unique context. Courtney preferred engineering projects that resulted in real-world impacts, similar to those Holly implemented. She expressed concerns with engineering lessons with no tangible community improvements. She was worried that such engineering lessons would affect her students adversely as in their community, "people have ideas, and nothing ever gets solved. Historically, that's just how things are, and it's a horrible way for kids to grow up thinking that their ideas will never lead to change."

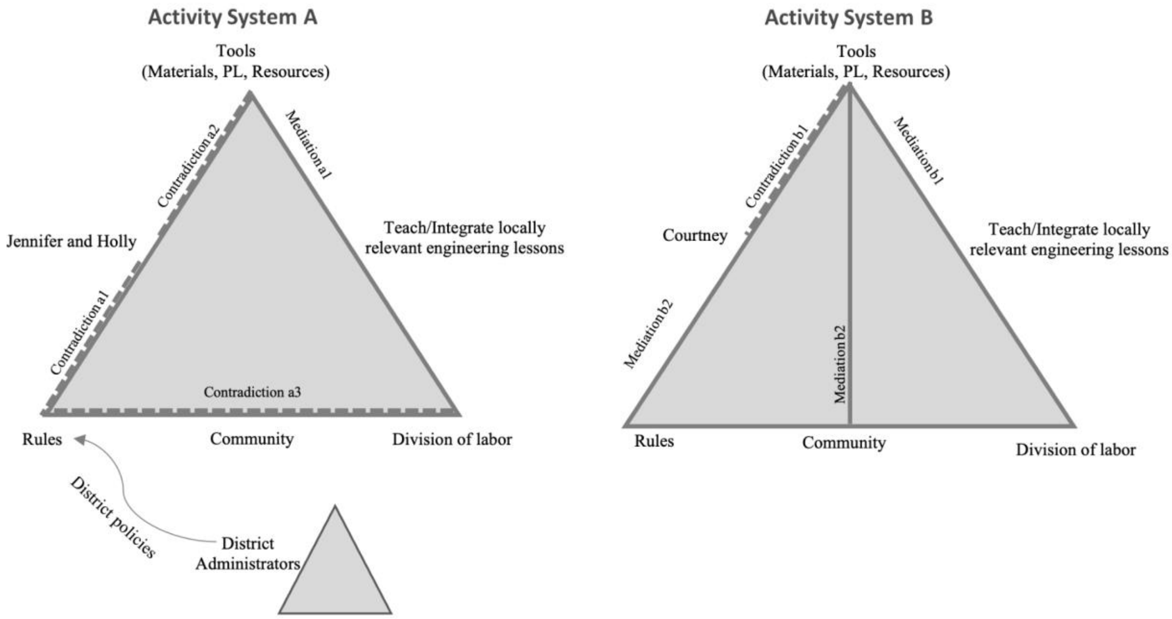
Discussion and Implications

In this paper, we explored how rural elementary school teachers sustain the implementation of locally relevant engineering lessons after the conclusion of a five-year nationally funded project. This project aimed to enhance rural and Indigenous students' awareness of engineering and related careers. It provided teachers with professional development, resources, and support to design and implement engineering lessons and curricula by incorporating their students' local and cultural contexts into their engineering teaching practices to increase engineering relevance and a sense of belonging for their students.

The sustainability of innovative teaching practices, such as engineering education in rural elementary schools, is a complex issue, and the differences in teachers' specific rural contexts posed different challenges for them to sustain the gains they received during the project. Teachers had varying levels of teacher autonomy and administrative support, and the availability of these alone did not ensure smooth implementation due to varied contextual differences. Therefore, based on the mediations and contradictions discussed above, we can claim that teachers belonged to different activity systems, and teacher agency and resource availability seemed to be the primary catalysts to mediate or contradict their unique activity systems (see Figure 4).

Figure 4

Triads for Activity Systems A and B



Note. Dashed lines indicate contradictions across elements of activity systems.

Jennnifer and Holly were part of Activity System A where administrative support for engineering education was inconsistent and, at times, even discouraging. On the other hand, Courtney operated within Activity System B, where she had greater autonomy to decide how frequently and in what ways to incorporate engineering lessons into her classroom.

In both activity systems (Tools: mediation a1 and b1), student engagement and enthusiasm pushed teachers to sustain the integration of locally relevant engineering lessons in their classrooms.

In Activity System A, Jennifer and Holly faced multiple conflicts which decreased the amount of engineering they taught after the cease of the project. One major challenge was the decline of teacher agency due to changing and evolving district policies and scheduling constraints, which resulted in less flexibility for them to integrate engineering into their classrooms (Rules: contradiction a1). They also indicated that after the project ended, they had misalignment between available engineering resources and their community problems. For example, Jennifer taught in a rapidly growing rural area with community problems changing fast, and it was a challenge for her to be aware of these problems and find relevant engineering resources that would tackle these community problems (Materials: contradiction a2). Furthermore, administrative decisions often deprioritized science and engineering in favor of core curriculum areas such as math or English language arts (ELA). Even though Jennifer was able to teach some engineering in her ELA classes using the resources she obtained through the project, teachers were also forced to restrict their engineering lessons and adapt their roles to fit within the evolving expectations of their schools and school districts (Division of labor: contradiction a3).

On the other hand, in Activity System B, Courtney did not face many contradictions, and she was more optimistic about sustaining engineering lessons in her classroom. She had access to funding through her community partnerships (Community: mediation b2). Her major obstacle to the sustainability of engineering integration was the inconsistent availability of materials, which would enable Holly to directly target their community problems and help her students experience the tangible impact of locally relevant engineering lessons, reinforcing their roles in solving real-world community challenges and their engineering identities.

In the literature, it is well known that rural is multidimensional, encompassing a wide range of social, economic, and cultural contexts that vary significantly from one community to another (Inouye et al., 2024; Hargreaves et al., 2009). Our analysis showed us that rural areas are not static places; rather, they are dynamic environments where community needs, resources, and educational priorities continuously evolve. Therefore, in providing professional learning in engineering, or any STEM field, that builds on local knowledge and targets rural teachers, we have concluded that it is significant to consider that teachers in these settings need to adapt to shifting policies, availability of resources, or growing communities with evolving community problems. In particular, our study showed that engineering education in rural schools is shaped by complex interactions between teacher agency and autonomy, administrative expectations and schedule constraints, and community engagement and resources. Understanding these dynamics is significant to design and develop targeted and context-specific professional learning opportunities to meet the unique needs of rural teachers and support them in sustaining professional development gains. We should also add that even though the literature using Activity theory (e.g., Cole, 2016) or focusing on education changes (e.g., Nocon, 2004) discusses these dynamics broadly–often without making any distinction between urban or rural contexts, our study provides a nuanced perspective specific to rural settings. Our study also contributes to the literature by emphasizing unique challenges rural schools face (e.g., rapidly shifting community needs and evolving administrative expectations) and unique opportunities rural schools offer (e.g., for community engagement and contextually/locally relevant engineering) and suggesting that these challenges and opportunities play a critical role in shaping the sustainability of engineering learning practices in rural schools.

Conclusion and Limitations

We conclude that achieving sustainable change in engineering teaching practices is not merely a consequence of initial training or projects but requires a collective effort that addresses variations across school/classroom contexts (e.g., Sandholtz & Ringstaff, 2016). We should also note that the implications of this study extend beyond engineering education and deepen our understanding of the complexities involved in sustaining teacher professional learning outcomes in rural school districts. This study calls for a multifaceted approach that involves teachers, administrators, and the broader community in fostering an environment that supports lasting educational change. To sustain teacher gains from STEM professional development programs in rural areas, we recommend that these programs should account for fluctuating levels of teacher autonomy/agency and the shifting administrative expectations, and can explicitly build on ongoing community engagement, funding pathways (using local partnerships), and adaptable materials to evolving community needs and local problems.

In terms of the limitations of the study, our primary data sources were teacher interviews, and we did not collect data from administrators (principals or district administrators); therefore, administrators' activity systems were missing in our study. Future research could benefit from field observations, administrator perspectives, and a wider range of rural schools.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

References

Avery, L. M., & Kassam, K.-A. (2011). Children's local rural knowledge of science and engineering. *Journal of Research in Rural Education, 26*(2).

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Bowen, B., Shume, T., Kallmeyer, A., & Altimus, J. (2021). Impacts of a research experiences for teachers program on rural STEM educators. *Journal of STEM Education: Innovations and Research, 22*, 4. https://jstem.org/jstem/index.php/JSTEM/article/download/2541/2242

Boz, T., & Allexsaht-Snider, M. (2022). How do elementary school teachers learn coding and robotics? A case study of mediations and conflicts. *Education and Information Technologies, 27*(3), 3935–3963. https://doi.org/10.1007/s10639-021-10736-4

Coburn, C. E., Russell, J. L., Kaufman, J. H., & Stein, M. K. (2012). Supporting sustainability: Teachers' advice networks and ambitious instructional reform. *American Journal of Education*, *119*(1), 137–182. https://doi.org/10.1086/667699

Cole, M. (2006). The distributed literacy consortium. *The fifth dimension: An afterschool program built on diversity.* Russell Sage.

Cole, M. (2016). Designing for development: Across the scales of time. *Developmental Psychology, 52*(11), 1679–1689. https://doi.org/10.1037/dev0000156

Dalvi, T., & Wendell, K. (2015). Community-based engineering. *Science and Children, 53*(1). https://doi.org/10.2505/4/sc15_053_01_67

Drits-Esser, D., Gess-Newsome, J., & Stark, L. A. (2017). Examining the sustainability of teacher learning following a year-long science professional development programme for inservice primary school teachers. *Professional Development in Education*, *43*(3), 375– 396. https://doi.org/10.1080/19415257.2016.1179664

Engeström, Y. (1999). Innovative learning in work teams: Analyzing cycles of knowledge creation in practice. *Perspectives on activity theory*, *377*, 404.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133–156.

El-Hamamsy, L., Monnier, E.-C., Avry, S., Chevalier, M., Bruno, B., Dehler Zufferey, J., & Mondada, F. (2024). Modelling the sustainability of a primary school digital education curricular reform and professional development program. *Education and Information Technologies*, *29*(3), 2857–2904. https://doi.org/10.1007/s10639-023-11653-4

Gallagher, S., & Woolard, C. (2022). Professional development outcomes for rural teachers participating in a Research Experience for Teachers program in innovative transportation systems (evaluation). 2022 ASEE Annual Conference & Exposition. https://sftp.asee.org/40562.pdf

Hargreaves, L., Kvalsund, R., & Galton, M. (2009). Reviews of research on rural schools and their communities in British and Nordic countries: Analytical perspectives and cultural meaning. *International Journal of Educational Research, 48*(2), 80–88. https://doi.org/10.1016/j.ijer.2009.02.001

Hammack, R., Lux, N., Gannon, P., & LaMeres, B. (2021, July). *Using ethnography to enhance elementary teachers' readiness to teach engineering.* In ASEE Annual Conference Proceedings.

Howard, S. K., Schrum, L., Voogt, J., & Sligte, H. (2021). Designing research to inform sustainability and scalability of digital technology innovations. *Educational Technology Research and Development*, *69*(4), 2309–2329.

https://doi.org/10.1007/s11423-020- 09913-y

Hubers, M. D. (2020). In pursuit of sustainable educational change: Introduction to the special section. *Teaching and Teacher Education*, *93*. https://doi.org/10.1016/j.tate.2020.103084

Hubers, M. D., Schildkamp, K., Poortman, C. L., & Pieters, J. M. (2017). The quest for sustained data use: Developing organizational routines. *Teaching and Teacher Education*, *67*, 509–521. https://doi.org/10.1016/j.tate.2017.07.007

Inouye, M., Macias, M., Boz, T., Lee, M. J., Hammack, R., Iveland, A., & Johansen, N. (2024). Defining rural: Rural teachers' perspectives and experiences. *Education Sciences, 14*(6), 645. https://doi.org/10.3390/educsci14060645

Kaptelinin, V. (2005). The object of activity: Making sense of the sense-maker. *Mind, culture, and activity*, *12*(1), 4–18.

Kennedy, M. M. (2016). How does professional development improve teaching? *Review of Educational Research, 86*(4), 945–980. https://doi.org/10.3102/0034654315626800

Leontiev, A. N. (1982). *Problems of the development of the mind.* Progress. (Original work published 1959).

Liou, Y.-H., Canrinus, E. T., & Daly, A. J. (2019). Activating the implementers: The role of organizational expectations, teacher beliefs, and motivation in bringing about reform. *Teaching and Teacher Education*, *79*, 60–72. https://doi.org/10.1016/j.tate.2018.12.004

Mendenhall, M. P., Tofel-Grehl, C., & Feldon, D. (2022). Rural teacher attitudes and engagement with computing and technology. *Theory & Practice in Rural Education, 12*(2), 179–196. https://doi.org/10.3776/tpre.2022.v12n2p179-196

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory Into Practice, 31*(2), 132–141. https://doi.org/10.1080/00405849209543534

Nocon, H. D. (2004). Sustainability as process: Community education and expansive collaborative activity. *Educational Policy, 18*(5), 710–732. https://doi.org/10.1177%2F0895904804269181

National Academies of Sciences, Engineering, and Medicine. (2024). *K–12 STEM education and workforce development in rural areas.* National Academies Press. https://doi.org/10.17226/28269.

Rigby, J. G., Woulfin, S. L., & März, V. (2016). Understanding how structure and agency influence education policy implementation and organizational change. *American Journal of Education*, *122*(3), 295–302. https://doi.org/10.1086/685849

Roth, W. M., & Lee, Y. J. (2007). Vygotsky's neglected legacy: Cultural-historical activity theory. *Review of Educational Research*, *77*(2), 186–232.

Sandholtz, J. H., & Ringstaff, C. (2016). The influence of contextual factors on the sustainability of professional development outcomes. *Journal of Science Teacher Education*, *27*(2), 205–226. https://doi.org/10.1007/s10972-016-9451-x

Shume, T., Bowen, B. D., Altimus, J., & Kallmeyer, A. (2022). Rural secondary STEM teachers' understanding of the engineering design process: Impacts of participation in a Research Experiences for Teachers program. *Theory & Practice in Rural Education, 12*(2), 89–103.

Sobel, D. (2004). Place-based education: Connecting classrooms and communities. *Education for Meaning and Social Justice, 17*(3), 63–64.

Sprowles, A., Goldenberg, K., Goley, P. D., Ladwig, S., & Shaughnessy, F. J. (2019). Place-based learning communities on a rural campus: Turning challenges into assets. *Learning Communities: Research & Practice, 7*(1), 6. https://files.eric.ed.gov/fulltext/EJ1218557.pdf

Stake, R. E. (2006). *Multiple case study analysis.* The Guilford Press.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Sage.

Tan, E., Calabrese Barton, A., & Benavides, A. (2019). Engineering for sustainable communities: Epistemic tools in support of equitable and consequential middle school engineering. *Science Education, 103*(4), 1011–1046. https://doi.org/10.1002/sce.21515

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

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