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Board 298: Supporting Elementary Engineering Instruction in Rural Contexts Through Online Professional Learning and Modest Supports

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Introduction

Despite the intent to advance engineering education with the Next Generation Science Standards (NGSS) [1], teachers across all grade levels lack self-efficacy in their engineering content knowledge and pedagogy [2]. Research shows that teacher self-efficacy impacts not just quality of instruction, but teacher resilience and student outcomes as well [2], [3]. This dilemma is exacerbated by a lack of quality NGSS-aligned curricular materials that integrate science and engineering at the elementary grades—currently, only one elementary unit reviewed by Achieve has received an NGSS Design Badge that includes engineering [4], and these materials are especially unavailable in schools serving high-needs students [5]. Due to geographic location and, often, smaller collegial networks of teachers who teach science and engineering, rural schools encounter acute challenges in recruiting and retaining teachers [6] and providing content-specific Professional Learning (PL) [7]. The goal of this NSF DRK12 multi-institution project is to expand on the work of Sandholtz and colleagues [8] and longitudinally investigate the impacts, sustainability, and costs of NGSS implementation, especially in rural contexts. Our approach is tailored to rural educators in grades 3–5 and offers curriculum-agnostic, fully online PL that supports teachers in utilizing resources and phenomena found in their local contexts to develop and implement NGSS-aligned engineering instruction, without a focus on a specific engineering discipline.

Conceptual Framework

The integration of engineering within *A Framework for K-12 Science Education* is a revolutionary addition and a part of the paradigm shift encompassed in the three-dimensional approach to STEM instruction described by the NGSS [4], [9]. Engineering education allows students to authentically apply content related to real-world phenomena so they can understand how the intertwined nature of science and engineering addresses the community and global issues they are facing today. Engineering education better prepares students to think critically, make decisions, and pursue STEM careers and educational trajectories. Yet many teachers, particularly in elementary grades, lack sufficient professional development and self-efficacy to include engineering in their curricula and embed it in meaningful ways that connect to students' lives and communities. This phenomenon is augmented along gender, geographic, and socioeconomic lines [10-13]. Teacher self-efficacy in any content area is a strong predictor of both student motivation and learning outcomes; this is particularly notable in STEM domains, where teachers' perceptions of their own STEM knowledge are shown to directly affect the effectiveness of their instruction [3], [10], [14]. Therefore, understanding the components and conditions of professional development that will have the greatest impact on teachers' engineering education self-efficacy, particularly across various subgroups, is essential for providing more meaningful teacher training to impact practice.

Self-efficacy

Albert Bandura's Social Learning Theory [15], [16] provides a valuable starting point for describing elements of professional learning that best support positive changes in teacher self-efficacy. Social Learning Theory describes that humans at all developmental stages learn through their interactions with others. This learning occurs via three components, i) observation, ii) imitation, and iii) modeling. An individual learns by watching and imitating an effective role model and by contextualizing this information in relation to desired outcomes. This process may be effectively applied to professional development in that a teacher may shape his or her pedagogical behavior by observing a master teacher through a vicarious teaching experience and may subsequently imitate that behavior to practice and assimilate it in their own classroom.

Inherent in Social Learning Theory is the construct of *self-efficacy*, which is a person's conviction that one can successfully produce desired outcomes [15], [16]. Bandura further describes two dimensions of self-efficacy: efficacy expectation and outcome expectancy. Efficacy expectation is a person's belief that they can successfully perform the behavior required to achieve the desired outcome, while outcome expectancy is the belief that carrying out that behavior will result in the expected outcome. Self-efficacy arises from four sources: mastery experiences (in which an individual experiences success), vicarious experiences (those in which an individual observes a role model succeeding in a particular area), physical and emotional/affective states (positive emotions or physiological responses to that context), and social or verbal persuasion (feedback given by role models). These sources of self-efficacy point to components of professional learning that have the potential to impact teachers' perceptions of their ability to effectively teach engineering.

Self-efficacy to teach engineering is one's belief in their ability to positively affect students' understanding of engineering design [17]. Yoon and colleagues [17] have identified five domains that constitute engineering teaching self-efficacy: engineering knowledge self-efficacy, instructional self-efficacy, motivational and engagement self-efficacy, disciplinary self-efficacy, and outcome expectancy. Although still limited, research exploring teachers' engineering self-efficacy indicates that each of these domains may be impacted differently through professional development and intervention, with explicit reflection activities and those that support content and pedagogical mastery as having the greatest impact on teachers' overall engineering self-efficacy across the five domains [18].

Supporting Engineering Self-efficacy for Rural STEM Teachers

Rural schools offer STEM educators many benefits, including close-knit communities, greater teacher autonomy, and close relationships, all which can have positive outcomes for student achievement and teacher retention [19]. Yet despite the unique assets associated with rural communities and schools, there are also challenges faced by rural teachers that may impact their access to professional learning and, therefore, the opportunity to increase their engineering self-efficacy.

For many elementary teachers, factors that inhibit the development of teachers' engineering self-efficacy include lack of background knowledge, limited support for professional development and curriculum development, few resources and materials, and insufficient training in teaching to a new set of standards [11-13], [20-22]. Teachers who feel they do not understand the engineering learning standards and lack self-efficacy in their ability to craft lessons around them are less effective in teaching engineering, which negatively impacts student achievement and engagement in engineering, often reducing it to decontextualized activities that further distance students from seeing engineering as relevant to their lives.

Within rural educational communities, these factors may be further amplified because rural schools may face tight budgets and educators who are teaching across a variety of grades and subject areas. As such, content-specific or specialized training in areas such as engineering may not provide the best fiscal value for a school community [12]. Rather, professional learning that will be relevant to a broader group of teachers, such as trauma-informed practice, often tends to be the focus of such offerings.

Further, as rural school communities may be geographically distant, consultants, experts, and industry partners may be less likely to travel to these locations to offer professional learning or to partner with teachers, particularly if the training will be provided to only a small group [23], thus limiting teachers' access to learning opportunities within engineering education and outreach. Geographical locations may also impact teachers' ability to travel to other sites for professional learning, due to such factors as logistics, cost, and weather. These barriers may decrease not only teachers' access to learning but to opportunities for collaboration and networking with other educators, which are highly sought connections for rural educators.

These unique aspects of rural education and professional learning underscore the need for training that affords teachers in these spaces the opportunity to connect with each other, to engage in intentional experiences with relevant STEM tasks tied to their communities, and to leverage the assets their communities provide. These components also affirm the findings of [17] that engineering self-efficacy is fostered through learning that focuses on reflection, pedagogy, and content. This also aligns with the recommendation of Hargreaves et al. [24] who stress the importance of allowing teachers to network with peers who have shared goals, visions, and concerns related to teaching in rural spaces even when they teach in distinct locations.

High-quality professional learning experiences focused on providing efficacy building experiences can be effective at enhancing teachers' engineering teaching self-efficacy [25]. Key characteristics of effective teacher professional learning including those that are shown to increase engineering education self-efficacy are: 1) a focus on deepening teachers' content-specific knowledge; 2) active teacher engagement in learning activities; 3) sustained professional learning over time; 4) substantial contact hours; 5) connection to teaching practices within the professional learning; 6) collaboration and networking among participants, and 7) exposure to authentic, real-world engineering tasks connected to their lives and other content areas [20], [26-29]. Research is needed that highlights the most impactful practices for embedding these components into professional learning opportunities within the context of rural education.

Project Description

Participants

Project participants included 151 teachers from four states, California, Montana, North Dakota, and Wyoming, who taught across grades 3 through 5. Some teachers taught more than one grade and were labeled as multi-grade. For this paper, we only report on data from the 111 participants who completed both pre- and post-intervention surveys before and immediately following a summer professional learning (PL) institute. Table 1 shares a breakdown of the number of participants representing each state and grade level.

Table 1. *Counts of participants by state and grade level*

Grade Levels	**States**				
	California	**Montana**	**North Dakota**	**Wyoming**	**Total**
Grade 3	10	5	12	7	34 (30.6%)
Grade 4	7	5	5	6	23 (20.7%)
Grade 5	3	3	5	6	17 (15.3%)
Multi-grade	9	9	9	10	37 (33.3%)
Total	29	22	31	29	111 (100%)

Summer Professional Learning Institute

Our intervention began with a five-day online PL experience in the summer of 2023 for teachers in each of four western states. The weeklong institute was co-designed and delivered by K-12 Alliance, who are experienced online PL providers with many years of experience helping educators make sense of the NGSS. The PL was designed to enhance teachers' understanding of the instructional shifts called for by the Next Generation Science Standards (NGSS) and provide them with supports for using 1) three-dimensional instruction to support students' sensemaking of phenomena and solving problems; 2) authentic, relevant, and meaningful science and engineering instruction to supports all students; 3) instruction that builds on students prior knowledge and leverages students' resources and skills; 4) instruction that approximates the work of scientists and engineers; and 5) formative assessment opportunities to support students. Teachers completed synchronous and asynchronous activities as part of the PL each day, with each day designed to allow teachers to work collaboratively across different grade levels and states, providing multiple opportunities for teachers to learn about each other's unique contexts.

Engineering Professional Learning

For the purposes of this paper, we focus on describing only the engineering-specific components of the summer PL institute. The PL was designed to leverage our participating teachers' prior knowledge for teaching science as a means of introducing them to engineering. Teachers spent Days 1 and 2 becoming more familiar with the NGSS and learning about the SEPs, which helped them to learn to distinguish the use of scientific phenomena, engineering problems, and ways to incorporate practices into learning experiences. Activities included in the PL were purposefully selected to give teachers firsthand experiences in identifying problems and applying these practices. On Day 4, teachers worked collaboratively through a cycle of engineering design wherein they interviewed peers to learn about a specific weather-related problem they were facing. This followed the Stanford d.school Design Thinking Process (https://dschool.stanford.edu/resources/the-bootcamp-bootleg). Teachers designed a solution, solicited feedback, built a prototype, and tested it in their peer groups. To start this activity, the facilitator began by having participants think about their experiences with extreme temperatures and the impacts they can have on communities. Next, participants were provided with a link to NOAA temperature data (www.weather.gov/wrh/climate) and explored the data set to identify the highest recorded temperature in their geographical area. Participants engaged in a "What do you notice? What do you wonder?" journaling activity. Working together in peer groups in breakout rooms, participants engaged in empathy interviews in which they were provided with the following prompt: "What would be meaningful to your partner to protect from extreme heat?" During the breakout rooms, they took turns interviewing each other to gather information related to the prompt. On the second day of engineering-specific learning, participants used the information they gathered from their partner and worked to design five possible solutions to their partner's extreme temperature-related problem. The participants shared their design ideas and gathered feedback from their partners. Then, the participants selected one design solution and constructed a prototype of their final design.

Data Sources

We administered the Teacher Efficacy and Attitudes toward STEM (T-STEM) Survey [30] before and immediately following the summer PL institute. Our sample of 111 teachers completed these surveys pre- and post-intervention. We used the Engineering Teaching Efficacy and Beliefs subscale and the Engineering Teaching Outcome Expectancy subscale of the T-STEM Survey, which employed a five-point Likert scale ranging from Strongly Disagree (scored as 1) to Strongly Agree (scored as 5).

Data Analysis

We used SPSS version 29 and ran paired samples t-tests to measure the changes in teachers' scores in engineering teaching efficacy and outcome expectancy. We also reported the effect sizes (Cohen's *d*) to measure the magnitude of the changes from the pre-survey to the postsurvey scores.

Preliminary Findings

The results of the paired samples t-tests indicate significant increases from the pre-survey to the post-survey for both measured constructs (see Table 2 and Figure 1). For Engineering Teaching Efficacy, the mean score significantly increased from 2.97 (SD = 0.65) pre-survey to 3.73 (SD = 0.43) post-survey, $t(110) = -12.56$, $p < .001$, with a Cohen's d effect size of 0.64, indicating a medium to large effect (Cohen, 1988). For Engineering Teaching Outcome Expectancy, there was a significant increase in the mean score from 3.46 (SD = 0.49) pre-survey to 3.64 (SD = 0.54) post-survey, $t(110) = -3.97$, $p < .001$, with a Cohen's d of 0.47, suggesting a medium effect size (Cohen, 1988). These findings suggest statistically significant increases in both teaching efficacy and outcome expectancy following the summer PL institute. Therefore, the initial intensive summer PL experience had immediate positive impacts on grades 3–5 teachers' attitudes and efficacy for teaching engineering. We are now exploring how modest supports influence the sustainability of these changes.

Table 2. *Results of paired samples t-tests*

	Pre-Survey		Post-Survey		*t*	*df*	*p*	Cohen's *d*
	M	*SD*	*M*	*SD*				
Efficacy	2.97	.65	3.73	0.43	-12.56	110	<.001	.64
Outcome Expectancy	3.46	.49	3.64	.54	-3.97	110	<.001	.47

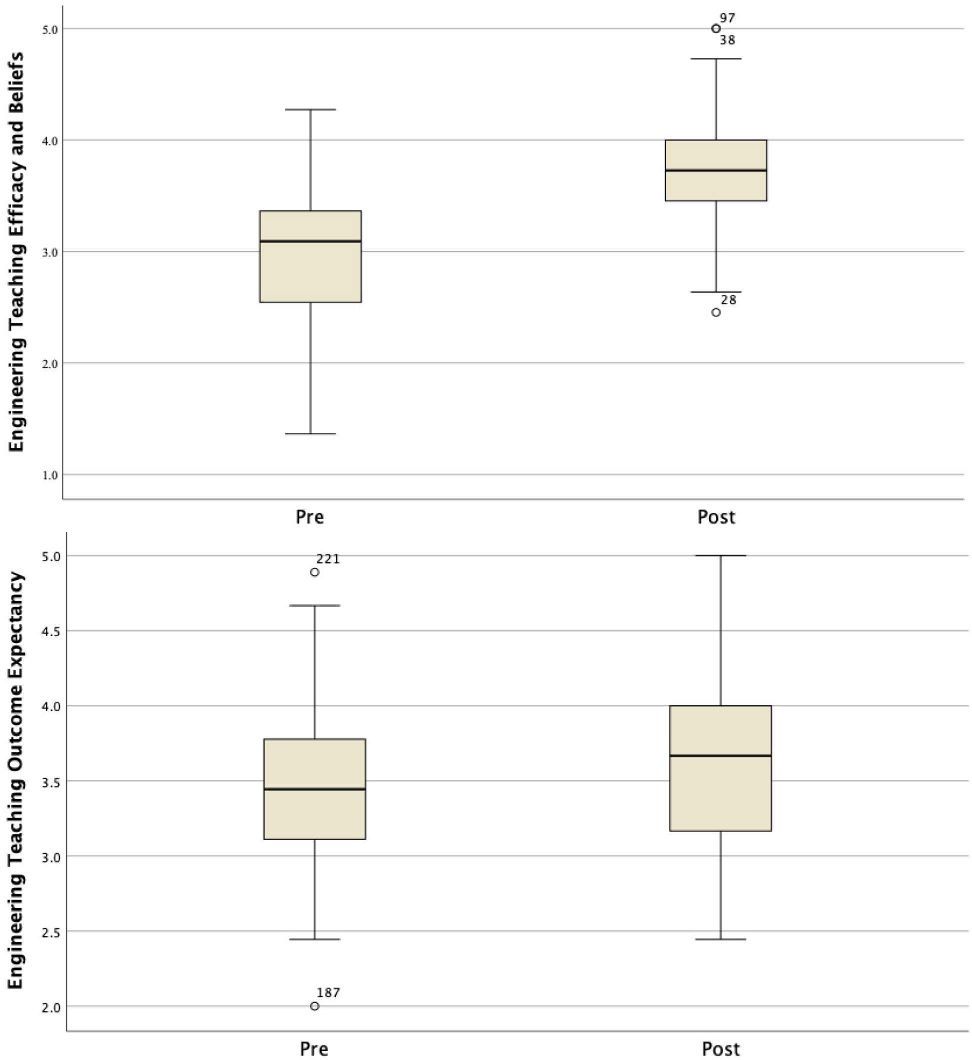

Figure 1. *Boxplots showing the changes in the self-efficacy scores*

Ongoing Modest Supports

The project is currently mid-way through the first of two years of planned modest supports with a cohort of elementary teachers. Over the 2023-2024 academic year, we are providing teachers with a menu of modest supports to sustain their PL: seven 90-minute-long online sessions as professional learning communities (PLC), materials for teaching a locally focused engineering design task, and access to a variety of electronic supports (e.g., Google Classroom Site, shared resources). For the purpose of this paper, we focus the remainder of this description on the engineering-specific modest supports. This included two online PLC sessions that were engineering-focused and engaged participating teachers from all four states over Zoom.

During Fall 2023, we held two 90-minute-long PLC sessions focused on engineering design. Prior to the first of these sessions, we had participants complete a community walk [31], to learn more about the communities in which they teach. We asked participants to read Chapter 6 of

Teaching in Rural Places [32] and follow the steps to complete the community walk. When completing the community walk exercise, we also asked that they pay attention to science and engineering connections in their local community. We then had them create a single Google slide to share highlights of what they learned with the entire group. After a brief check-in and icebreaker activity, we placed participants in breakout rooms with teachers from other states and had them share their community walk slides with each other as a way to build community amongst participants. After this sharing session, participants came back to the main room, where the presenters gave a brief refresher of the extreme weather engineering-specific activities from the summer PL.

Next, the presenters introduced participants to the Culturally Relevant Engineering Design (CRED) Framework [33], which is the framework the participants then used when designing their engineering lessons (see Figure 2). Participants were then placed back into the same breakout rooms and provided with a link to Jamboard where they spent 10 minutes talking about the extreme weather summer PL activities and identifying how the different components of the summer engineering activities aligned with the CRED. Then, we moved participants into state-level breakout rooms where they revisited their community walk slides. This time we had them focus on the science and engineering connections they noted during their community walks. The purpose of shifting back to the community walk slides was to get them thinking about their local contexts in preparation for the next portion of the PL, which required them to think about ways they might modify the extreme weather activities from the summer PL to be more closely aligned with weather concerns in their own communities. During this portion of the PLC we provided participants with a lesson plan template aligned with the CRED and had them start working on the first phase of the template (identify the problem). We ended the PLC session by asking participants to spend time completing the identify and describe phases of the CRED lesson plan template before the next PL meeting.

The second engineering-focused PLC session was held approximately six weeks after the first PLC session with separate meetings occurring for each of the four states (CA, MT, ND, & WY). The focus of this smaller, state-level PLC was to allow participants to spend time planning the details of their engineering lesson plans. Participants were placed in grade-level breakout rooms to work on the remaining sections of the CRED lesson plan template. While each participant's lesson was being customized for their specific community, we chose to place teachers in grade level groups to provide them with opportunities to brainstorm and collaborate with other same grade teachers from their state, as this is often not an option for teachers who work in small, geographically isolated rural communities. At the end of the 90-minute PLC, we tasked teachers with finalizing and teaching their lesson plan by the end of January 2024.

To further support their engineering lesson planning, we offered teachers multiple resources through the project's Google Classroom including the CRED lesson plan template, an overview of potential NGSS connections, links to additional resources on weather data, and a Padlet where teachers could continue to brainstorm and share resources with one another. In addition to these modest supports, which were provided to all participants, the research team purposefully selected five teachers from each state to participate in additional modest supports as part of an engineering learning community (ELC). The ELC members received Swivl robots to record themselves while teaching the engineering lesson they developed. We will hold two additional meetings with the ELC members during the spring semester, providing them opportunities to share their experiences teaching the lessons and to reflect on areas where they either struggled or would like to grow their practice or comfort level with engineering instruction. During the second year of the program, the project team will provide PL sessions focused on how to identify an opportunity for centering a community-related design task, and participants will develop and teach lessons connected to their individually identified community opportunities.

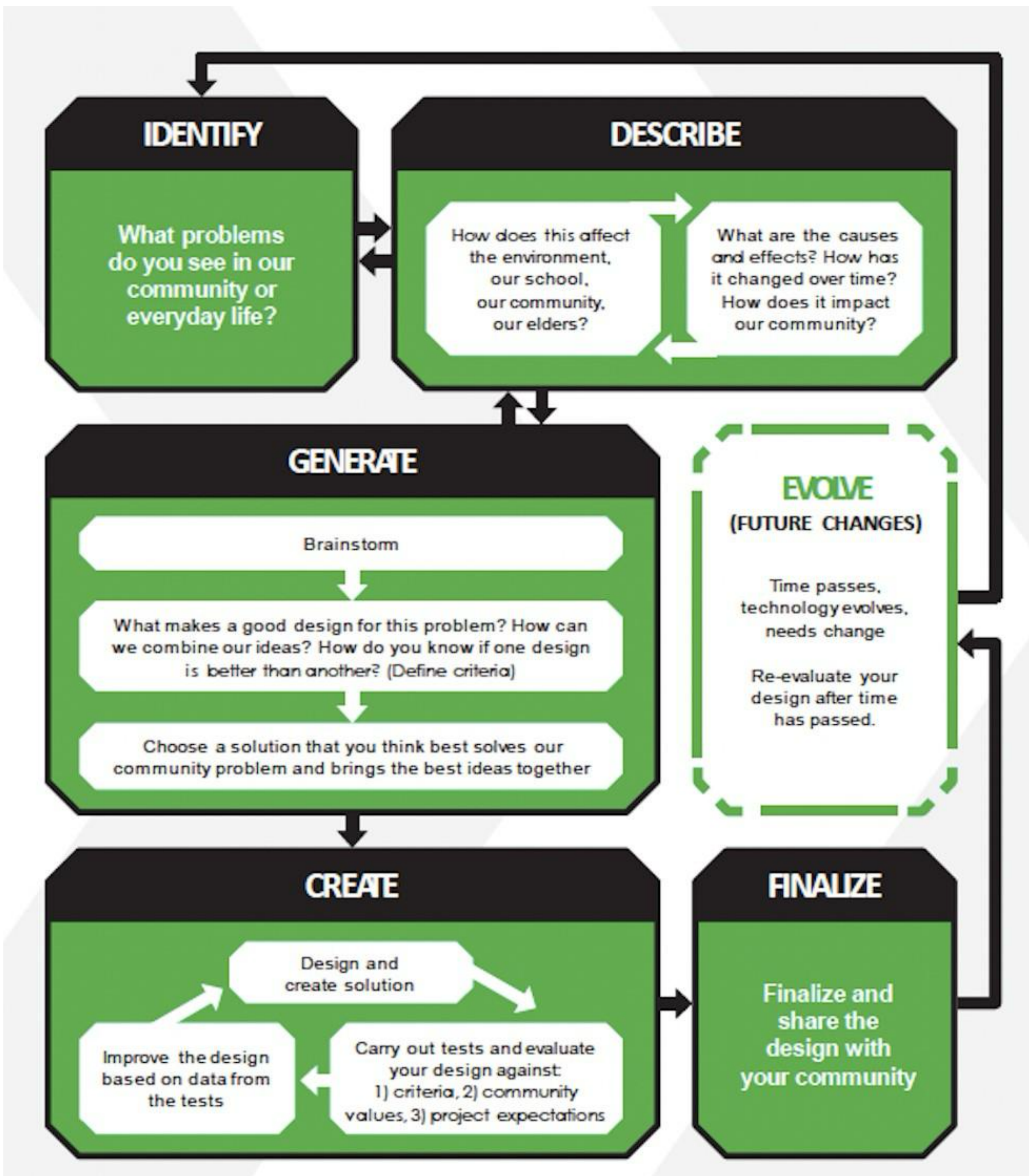

Figure 2. *Culturally Relevant Engineering Design (CRED) Framework*

Nest Steps

The project team will collect additional survey data on teachers' engineering self-efficacy for analysis at the end of the first and second years of modest supports to determine the extent to which the modest supports helped sustain the engineering efficacy gains seen after the initial summer PL. The project team will also be analyzing the video-recorded lessons and holding individual interviews with the ELC members to explore their experiences modifying a general engineering lesson (the extreme weather lesson from the summer PL) to align it with the CRED and their specific communities.

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