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Impact of Professional Development in Culturally Relevant Engineering Design for Elementary and Middle School Teachers (RTP, Diversity)

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Abstract

Effectively teaching engineering within a culturally relevant framework [1] has the potential to dramatically increase student engagement, outcomes, and representation within STEM, particularly for students who have not historically seen science and engineering as relevant to their lives. Yet many teachers feel they lack the training and self-efficacy to include engineering in their curricula in ways that are meaningful and connect to students' lives and communities [2]. This paper describes results from a professional development (PD) program to help elementary and middle school teachers create and implement engineering design tasks in their classrooms that are relevant to the cultures and communities of their Native American and rural student populations and that are aligned with local STEM standards and curricula.

A total of 15 teachers from grades 3-8 in a range of subjects (Science, Math, Language Arts) participated in a full year of PD, including 5 days in the summer and 3 days during the academic year. Teachers implemented 3 culturally relevant engineering design (CRED) tasks that they designed for their own classrooms. A CRED framework was adapted from Guerra et al.'s [3] engineering design process to explicitly include connections to community, culture, and place within each design stage (Identify, Describe, Generate, Embody, Finalize). The PD program was built on a theoretical framework using Bandura's [4] Social Cognitive Theory to develop self-efficacy and collective efficacy within the teacher cohort. Teachers were given tools, practice, and support to develop their own CRED tasks. The cohort model provided opportunities for peer mentorship and on-going collaboration within and across school districts. PD sessions included time for teachers to develop lesson plans, explore resources, and reflect on their learning.

We used a mixed methods research design to investigate the impact of the PD program on teacher self-efficacy and classroom pedagogy with a focus on cultural relevance and engineering design. Quantitative pre/post data was collected using three survey instruments: Teaching Engineering Self-Efficacy Scale (TESS), Culturally Responsive Teaching Self-Efficacy Scale (CRTSE), and Culturally Congruent Instruction Survey (CCIS). Qualitative data included videotaped classroom observations, individual teacher interviews after each design task, and teacher focus groups and written reflections during the summer and school year PD days.

Study results showed a promising and consistent picture of increased teacher self-efficacy and changes to teaching practice. Statistically significant gains were seen in pre/post surveys, with specific gains that include increased self-efficacy related to "guid[ing] my students' solution development with the engineering design process" and "us[ing] examples that are familiar to students from diverse cultural backgrounds" and increased classroom use of "science activities in which students designed solutions to problems relevant to their community." Teachers also report increased engagement from all students, particularly among previously struggling and disengaged students who took on greater leadership, and female students who showed greater confidence and engagement. Teachers also noted increased student capacity for independence, creativity, problem-solving, and productive collaborative work.

1. Overview

The integration of engineering within K-12 education is a revolutionary addition to standards and is part of the paradigm shift encompassed in the three-dimensional approach to STEM instruction described by the Next Generation Science Standards (NGSS) [5]. Engineering education allows students to authentically apply content related to real-world phenomena so they can understand how the interdependent nature of science and engineering address many of the local and global societal issues they are facing today. This focus has major implications for elevating STEM instruction in classrooms and can situate engineering as an equity-centered endeavor that can provide greater access and inclusion for students who have been historically marginalized in traditional, Western-oriented science and engineering education, increasing opportunities for connection, creativity, and innovation that may have been absent in traditional STEM classrooms.

Effectively teaching engineering within a culturally relevant framework [1] has the potential to increase student engagement, outcomes, and representation within STEM, particularly for students who have not historically viewed science and engineering as relevant to their lives or as an area in which they can engage. Yet many teachers, particularly those in the elementary grades, lack training and self-efficacy to embed engineering in their curricula in ways that meaningfully connect to students' lives and communities [2]. Traditional "engineering" building tasks can disenfranchise students from non-dominant groups, particularly Indigenous communities, because there is a lack of connection to multiple epistemologies, specifically those focusing on cultural competency, identity, and relationships with the natural world [6]. Focusing on how engineering education can be reframed as equity-centered, inclusive of diverse voices and ways of learning, is essential to increasing participation and outcomes in engineering.

Supporting teachers in employing a culturally relevant approach to engineering requires new and improved professional development (PD) opportunities. One-time training activities, while useful for raising awareness of effective teaching practices, are ineffective at promoting long-term changes in teacher pedagogy; therefore, developing better PD models that will support and sustain engineering education implementation and embed it within culturally relevant pedagogy is essential to aligning teacher practice with the fundamental aims of NGSS.

This paper describes results from Project ExCEED (Exploring Culturally relevant Engineering Education Design), a professional development program designed to help elementary and middle school teachers create and implement engineering design tasks in their classrooms that are relevant to the cultures and communities of their Native American and rural student populations and that are aligned with local STEM standards and curricula. The program structure and activities incorporate principles from the literature regarding sources of teacher self-efficacy and PD design and are built around a new CRED framework that combines tenets of culturally relevant pedagogy and the engineering design process.

2. Theory & Current Practice

Bandura's Social Learning Theory [4], [7], which focuses on self-efficacy, guided the design and implementation of our PD. Social Learning Theory describes that humans learn through interactions with others via observation, imitation, and modeling. Self-efficacy is a person's "conviction that one can successfully execute the behavior required to produce the outcomes" [4], [7]. Self-efficacy arises from four sources: *mastery experiences* (an individual experiences success), *vicarious experiences* (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). Teacher self-efficacy in any content area is a strong predictor of student motivation and learning outcomes; this is particularly notable in STEM domains, where teachers' perceptions of their own STEM knowledge directly affect their instructional effectiveness [2], [8], [9], [10], [11], [12].

Teachers' collective efficacy, or the shared belief that teachers can collectively impact student outcomes [13], [14], is a crucial consideration in educational settings. Teachers' perceptions of collective efficacy are increased when they are empowered to collaborate around improved instructional practice with sources of self-efficacy in place [15]. On-going collaborative learning, active participation by teachers in learning, reflective discussions, integrating theory into practice, and building on the "thrill" of success are key components of effective PD for increased collective efficacy [15]. Increased collective efficacy also significantly impacts historically marginalized students [14], underscoring the importance of fostering both personal and collective efficacy within a PD setting.

Ladson-Billings' theory of culturally relevant pedagogy [1] describes three tenets that lead to a more equity-centered learning environment: 1) high expectations for all students, 2) cultural competency, and 3) critical consciousness. In other words, students must be held to high standards of achievement while developing and maintaining their cultural identity and being empowered to identify social inequities. Teachers must develop culturally relevant teaching self-efficacy and employ culturally responsive practice [16], the ability to use the cultural knowledge, prior experiences, and performance styles of diverse students, to make learning effective for them [12]. Ladson-Billings' framework of culturally relevant pedagogy [1] has been tested across cultural groups, including Native Americans, to validate these essential components for supporting student engagement and achievement. We situate our study and CRED framework within this construct to describe our culturally relevant approach to engineering education tied to students' lives and communities.

Self-efficacy to teach engineering is one's belief in their ability to positively affect students' understanding of engineering design [17]. Yoon, et al. [17] identified four domains that constitute teaching engineering self-efficacy: engineering pedagogical content knowledge self-efficacy, engineering engagement self-efficacy, engineering disciplinary self-efficacy, and engineering outcome expectancy. However, teachers across grade levels remain under-confident in their understanding of engineering content knowledge, pedagogy, and standards within NGSS [2], [10], [11]. This trend occurs throughout K-12; however, it is most prevalent at the elementary level, where teachers may possess less specific content expertise and teach all subjects, with female teachers, and in low-SES elementary schools [2]. This phenomenon emerges from various factors: lack of background knowledge, limited support for PD and curriculum development, few resources and materials, and insufficient training in teaching to a new set of standards [2], [18], [19], [20]. Teachers who feel they do not understand the engineering standards and lack confidence 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.

Bandura's [4] model of self-efficacy is often presented as direct and outcome-oriented; however, recent studies have offered a more cyclical illustration of impacts to self-efficacy. Tschannen-Moran *et al.* [21] described the interactive nature of sources of self-efficacy, explaining that, "teachers' performance in class is affected by their teaching self-efficacy, and, in turn, the outcome of their performance becomes the foundation of new sources of self-efficacy" [21], which can differ across subject areas and contexts. This model suggests the need to examine self-efficacy within context-specific domains and recognize the interactive nature of ability beliefs and sources of self-efficacy when examining teacher growth in practice.

To date, attempts to provide PD for K-12 educators in engineering education have remained limited and of narrow scope, with a dearth of research investigating models that increase culturally relevant engineering teaching practice and self-efficacy. Current approaches to engineering education PD address only isolated aspects of the components described in Social Learning Theory [4], [7] and often present an acultural view of engineering education. Teachers report positive responses to training in these scenarios, but little empirical evidence has shown lasting increases in self-efficacy or changes in pedagogy. Dare *et al*. [22] further posit that, while teachers desire strategies for integrating engineering into their content areas, a lack of meaningful PD in how to execute this has led them to distill engineering down to tasks that prioritize student enjoyment and soft skills, such as teamwork, over application of concepts; therefore, a lack of content knowledge and training often results in engineering tasks that do not include rigorous interdisciplinary connections even when teachers do incorporate engineering design into their instruction.

Very little literature exists that describes effective K-12 engineering education PD; however, findings suggest that working in cohorts on authentic, project-based engineering tasks supports teachers in feeling more comfortable with the content and with integrating such tasks into their classroom, leading to more lasting implementation of engineering education [18], [23], [24], [25], [26]. Reimers *et al.* [27] also proposed that there are five elements necessary in effective PD to promote the integration of engineering across the curriculum: 1) a focus on engineering content, 2) an emphasis on engineering pedagogical content knowledge, 3) a connection to how engineering design incorporates the application of other content areas, 4) exposure to engineering curricula, and 5) alignment to local and national standards.

Limited in the literature on effective K-12 engineering education PD is the incorporation of culturally relevant pedagogy to situate engineering within local communities and contexts. Literature states that PD on culturally relevant teaching is rarely presented in conjunction with engineering, which leads to further disparity among participating groups and a lack of teacher self-efficacy in making STEM concepts relevant to their students [28], [29]. Further, research on culturally relevant training and instruction tends to focus on African-American and Latinx students in urban settings, with few examining practices that impact Native American students in rural contexts [30], [31]. Pedagogical approaches that foster cultural relevance in science for Native American students include using community-situated topics; integrating inquiry, hands-on learning, and storytelling; incorporating Native epistemologies; and focusing on place-based learning; however, these elements are rarely explicitly taught in STEM PD [30], [31], [32], [33],

[34]. All studies exploring the impact of culturally relevant STEM PD for teachers in Native American communities were focused on science, and none addressed engineering design, limiting support for teachers in incorporating effective engineering that is relevant to all students, particularly those from Native American communities.

In a 2015 ethnographic study done in South Dakota examining under-representation of Native Americans in engineering [35], participants explained that one of the greatest barriers to their participation in engineering education was a perception of engineering as a privileged pursuit that had no relevance to their tribe or potential to help their communities [35]. Needs identified by the participants included a clear sense of how engineering could ameliorate poverty, a cultural emphasis on engineering in K-12 schools, and increased exposure to role models and systems of support in their communities [35]. Increasing a STEM workforce within Native communities has the potential to increase self-reliance, sovereignty, and the opportunity to directly impact a community's needs [35]. This requires that K-12 engineering education provides the conditions for Native American students to bridge multiple epistemologies: it must be culturally situated, incorporate culturally relevant ways of knowing, and be relevant to communities to reduce identified barriers to participation [6], [36], [37]. Teachers must also be adequately prepared through effective PD to implement culturally relevant engineering education to increase *all* students' interest and persistence in engineering and to align with the integration of engineering within NGSS. PD must be designed to meet the unique needs of the populations exhibiting the most dramatic under-representation, increasing access, resources, and collaboration for teachers in rural, lower-socio-economic, and Native American-serving schools to facilitate these shifts in teaching practice and teacher self-efficacy.

3. CRED Framework & Tasks

We frame engineering education within culturally relevant pedagogy; therefore, our PD model supported teachers in developing their individual and collective self-efficacy in these domains simultaneously and as inherently integrated through the use of our CRED Framework [38]. The CRED framework provides a guide for teachers to incorporate the tenets of Culturally Relevant Pedagogy [1] and the North Dakota Native American Essential Understandings [34] as essential components of the engineering design process. As shown in Figure 1, the CRED, adapted from Guerra *et al.*'s [3] engineering design process, explicitly includes connections to community, culture, and place, with each stage (Identify, Describe, Generate, Embody, Finalize), describing how that stage directly addresses community-situated engineering needs and the instructional moves that ensure it is situated within a culturally relevant framework. Using the CRED Framework as a guide, teachers designed culturally relevant engineering tasks by first examining their required content within the context of state standards to identify appropriate placement of engineering design tasks in their curricula. Teachers then considered issues that were relevant to their school communities to identify authentic areas of need that students could explore through engineering.

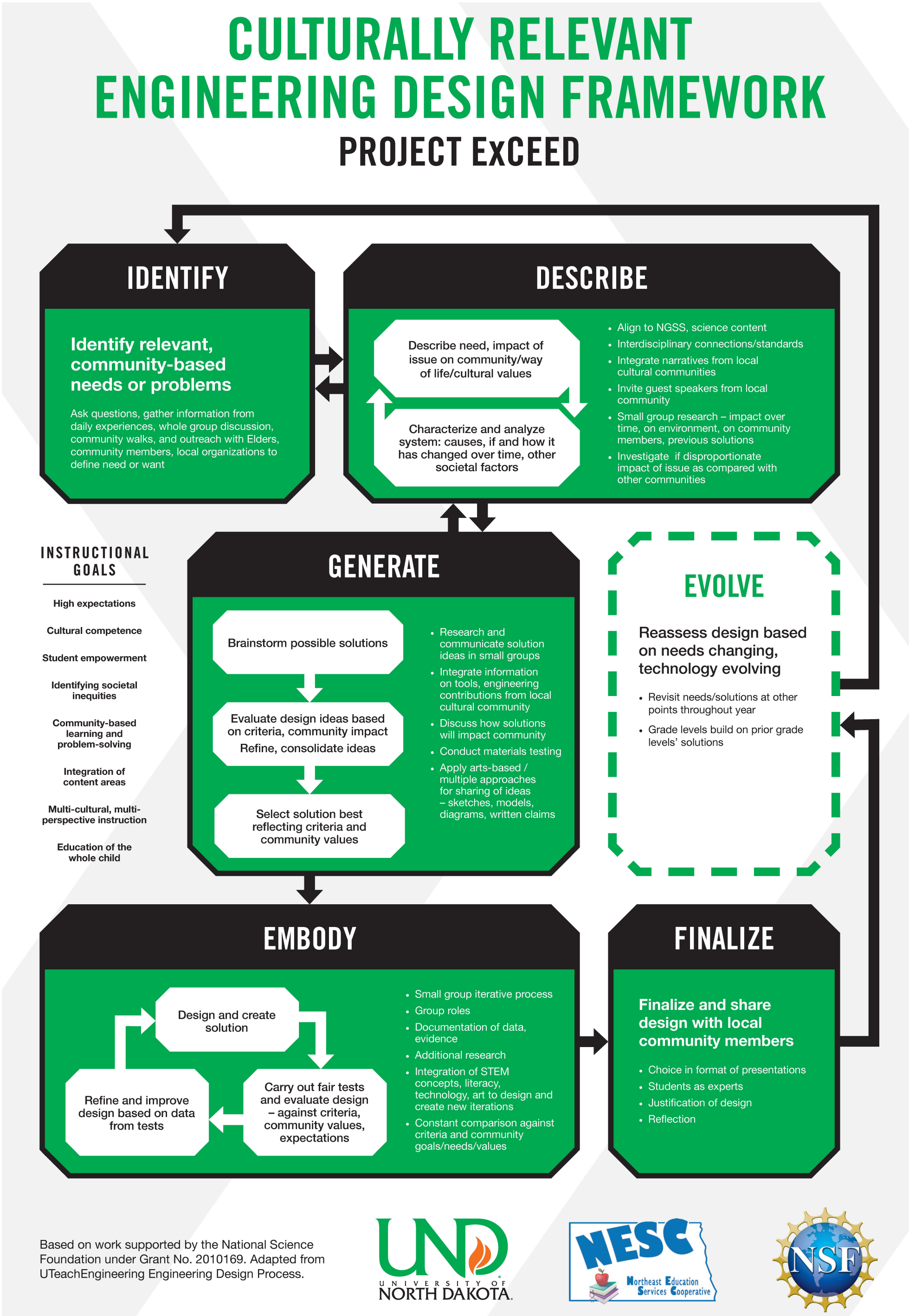

Figure 1. CRED Framework

An example of a CRED-aligned task designed by one teacher in the program involved a fourth grade NGSS standard [5] within the Earth Sciences domain (4-ESS2-2), which states that students will, "Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans." The fourth-grade teacher participant used this standard and the engineering performance expectation (3-5-ETS1-3) "plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved" to explore dam design with her students. The teacher first introduced the history of the Garrison Dam on the Missouri River to connect meaningfully to her students and the history of their region. The students learned that while the dam is a source of renewable energy and created a lake that provides many recreational opportunities, lands belonging to the Mandan, Hidatsa, and Arikara Nation were flooded to build this dam, and 90% of the community was displaced. This teacher delved deeply into the full history with her students, inviting community members who were impacted (many of her students' relatives) to come present to the class. As a result, the fourth-grade students engaged in the engineering design process to construct and test dam designs with the community context in mind, grappled with the ethics of engineering, and offered alternative solutions. This example demonstrates the power of connecting an engineering task to place, local history, and community and cultural contexts to increase relevance and importance for students.

Other CRED tasks developed by teachers included areas of interest such as: designing a filtration system to improve indoor air quality, developing a severe weather app to be used by teen drivers, creating a model of a proposed recreation center for the town, exploring different forms of shelter used in the Northern Great Plains climate, designing a greenhouse to prolong the community's growing season, and testing wind turbine blade designs. Each of these engineering design tasks had a direct connection to students' lived experiences and to their local community context, and teachers included students' voice and interests to drive the direction and extensions of the tasks.

While the focus of the PD was on incorporating engineering into science units situated within NGSS, we also promoted inclusion of engineering across content areas. Several participants in the program were not science teachers but found great success and increased student engagement by embedding culturally relevant engineering tasks within language arts, math, and social studies, highlighting how engineering can provide opportunities for students to gain deeper interdisciplinary understandings.

4. PD Program Model

The Project ExCEED PD program was designed by combining elements identified from prior research and theory (Table 1) with feedback from community stakeholders, teacher participants, and project advisory board. The overall goal was to use an ongoing, collaborative professional learning model to help teachers develop self-efficacy as they designed and implemented culturally relevant engineering design tasks in their own classrooms. The program intentionally embeds sources of self-efficacy while incorporating ongoing refinement to directly address the goals and aims of the participating school communities. Initial stakeholder input indicated a desire for authentic engineering tasks that bring students outside of the classroom and into the community, training in designing and implementing project-based and authentic STEM learning opportunities, increased frequency of STEM integration in classrooms, and training in strategies to increase engagement and achievement of Native American and economically disadvantaged students. Ongoing feedback was used to refine the PD design, which included key elements such as: ensuring ample time for collaboration, providing direct instruction in culturally relevant pedagogy, connecting with community and cultural resources, and focusing on assessment. The PD program included five days of Summer Institute training, three full-day Cohort meetings during the school year, and three engineering design tasks that teachers developed and implemented in their classrooms.

Table 1. Self-Efficacy Components in [Anonymous Program] PD

Self-efficacy Source	PD Conditions/Components included in our PD model and identified by participants
Vicarious Experiences	**Mentorship** from peers **Collaboration** through PLC's and cohort workshops "**Chunking**" learning – modeling/highlighting a pedagogical shift, allowing for time to explore, practice, incorporate into lessons
Mastery Experiences	**Autonomy** to customize curriculum development to students and local community **Iteration** – opportunity to review, revise, improve lessons based on measurable outcomes Focusing **pedagogical shifts/PD within one content area** creates relevance but allows for impact across all content areas
Affective States	Success/student engagement begets **positive affective state** leads to increased self-efficacy
Verbal persuasion	Support and collaboration from **administration** **On-going touchpoints,** check-ins for continuous learning, reflection, collaboration

Summer institutes

Teacher participants began the [Anonymous Program] PD program each year by attending two summer institutes offered within their local region. These institutes were held for three days in June and two days in August and included the focus areas and activities outlined in Table 2.

A series of learning opportunities were presented during the summer institute days by experts, including professional learning specialists, members of the research team, and Tribal members, with a focus on content and instructional practice to support classroom implementation of culturally relevant engineering. These summer sessions provide foundational understanding in the areas of culturally relevant pedagogy, NGSS and NGSS-aligned ND Science Standards, engineering design, facilitating effective collaborative work, and the North Dakota Native American Essential Understandings (NDNAEU) [34]. These focus areas prepared teachers with the skills and understandings to develop and implement project-based engineering tasks within the context of their classrooms, existing curriculum, and cultural settings. The summer institutes also gave teachers the opportunity to establish a much-needed network for collaborating on engineering curriculum development.

A key element of the PD design was having teachers work together in teams during the June session to complete a culturally relevant, community-situated engineering task to experience the CRED process as learners themselves. This task focused on a water filtration scenario that was situated in Native American cultural concepts, with the book "*We are Water Protectors*" [39] providing additional cultural grounding. To make connections with a local body of water, teachers explored the issues present in Devils Lake, including algal blooms from agricultural runoff, and how these phenomena impacted the community's use of the lake for recreation. The teachers also learned more about the Indigenous relationship to the lake from Elders from the Spirit Lake Nation and how the lake has changed over time. Teachers then designed, developed, tested, and refined water filtration systems, using water from Devils Lake itself, as outlined in the CRED. As they worked on the design task the importance of each engineering design framework step was discussed, and then the teachers emulated that portion of the process. During the entire design process, emphasis was placed on connecting engineering design to their community and to local tribal communities.

Table 2. Summer Institute Focus Areas and Activities

Month	Day	Focus areas	Activities
June	1	Culturally Relevant Engineering and the CRED Framework	• Experiencing a Culturally Relevant Engineering Task (water filtration) as learners • Exploring the Identify, Describe, and Generate stages of the CRED Framework • Introduction to Engineering in NGSS • Engineering as equity-centered - case studies
	2	Returning to Culturally Relevant Engineering, the CRED, and Navigating the NGSS	• Reading and navigating the NGSS • Examining strategies & pedagogy for teaching engineering • *Developing a Culturally Responsive Mindset* • Strategies for culturally relevant instruction • Continuing to experience water filtration as learners • Experiencing Embody and Finalize stages of the CRED
	3	Planning for Culturally Relevant Engineering tasks in classrooms	• Introduction to the North Dakota Native American Essential Understandings • Deeper dive into NGSS - examining the practices, disciplinary core ideas, cross-cutting concepts, and role of phenomena • Crosswalk of NGSS and ND state standards • Using a backwards design process for planning engineering tasks • Identifying grade level standards for developing tasks
Aug	4	Planning for Culturally Relevant Engineering Tasks in Classrooms & Collaborative work	• Strategies for supporting small group work in classrooms • Examining and planning for assessment in engineering • Culturally Relevant Engineering Task design and development • Peer feedback on tasks
	5	Final day – Integration, review, and presentation of Culturally Relevant Engineering Design Tasks	• Completion of engineering task development • Collaboration and sharing from local Elders around Indigenous relationship with water • Sharing of tasks/presentations • Session for administrators in providing school-based support • Scheduling of task administration for school year

The August session then focused on helping teachers modify the water filtration task for use within their own classrooms, building from their PD experience with *observing and modeling the culturally relevant engineering design process* to then *imitate* this approach. Teachers adapted the task to reflect NGSS standards for their specific grade level and connected the water filtration task to their unique classroom and community.

Cohort meetings

A key aim of the PD design is developing a strong and supportive cohort because collaborative experiences greatly impact the effectiveness of PD as well as the collective self-efficacy of the group members [13], [14], [15], [25], [40], [41], [42]. Teachers developed their strengths and expertise in implementing the CRED framework over the course of their participation in the project so that they could then act as peer mentors for each other, supporting the conditions to build the group's collective efficacy through a cohort model. Starting in the summer institutes, teacher participants work as a cohort to navigate the learning together. Teacher cohorts then met another three times during the school year, in fall, winter, and spring, for additional full-day cohort meetings. These meetings were scheduled prior to administering each of their three engineering design tasks. The purpose of these cohort meetings was to: 1) allow teachers to continue to collaborate with and support each other; 2) provide opportunities to co-plan and prepare engineering design tasks for their classrooms; 3) allow teachers to share experiences, successes, and challenges; 4) receive ongoing feedback and support from professional learning specialists and members of the research team; and 5) give teachers the opportunity to express their own needs for support and training to drive upcoming sessions. Our goal for these cohort meetings was not to present a great deal of new information, but rather to give teachers the time, support, and resources necessary to develop authentic and meaningful engineering design tasks so that they are prepared and feel confident in delivering them.

Classroom engineering design tasks

Teachers designed their own culturally relevant engineering tasks by first examining their required content within the context of state standards to identify appropriate placement of engineering design tasks in their curricula. Teachers considered issues that were relevant to their school communities to identify authentic areas of need that students could explore through engineering, beginning with the water filtration task described above as their first scenario and then engaging students to identify additional contexts for the other two tasks. We emphasized that the tasks teachers were creating should reflect the engineering design process and practices and provide the opportunity to assess student application and understanding of specific concepts by addressing meaningful curricular connections. These tasks were not meant to be administered simply for their own sake, but as an integral part of the unit for which they were created.

Task administration followed a model of gradual-release-of-responsibility, affording initial guidance to teachers to learn from experts and develop their self-efficacy with culturally relevant engineering pedagogy over time. Teachers took on increasing levels of responsibility for designing and implementing each task, with continued support from the research team but with increased collaboration, expertise, and modeling from participants themselves. For example, in each of the cohort meeting days we embedded opportunities to conference one-to-one with members of the research team and in small groups to brainstorm task ideas and receive support with resources and design development.

Teachers were videotaped when administering their design tasks for later observation by members of the research team and other members of their cohort. The research team used the videos to identify the impact on practice and areas needing additional support. Teachers used them to share successes, reflect on their practice, and provide feedback and support to each other. These video observations helped inform their instruction and provided data for creating relevant goals for teaching future tasks. This element speaks directly to the concept of social and verbal persuasion from Bandura's Theory of Self-Efficacy [4], [7].

Design considerations for meeting the needs of diverse communities

The aim of Project ExCEED was to improve the learning environment and experience for students from rural and Indigenous communities across North Dakota, with a design that **is culturally relevant** and supports the full participation of all learners, bridging the gap between cultural knowledge and practices and "mainstream" science and engineering [6]. The approach to engineering education and PD was explicitly grounded in culturally relevant pedagogy and Indigenous ways of knowing. Teachers were provided direct training in developing their culturally responsive practice in collaboration with learning specialists from the Climate, Culture, and Courage Project [43]. We framed our PD within the North Dakota Native American Essential Understandings (NDNAEU) (Figure 2) [34], which identifies elements critical to Native American ways of knowing, relating, contributing to local and global society, and sustaining their sense of identity and culture. The NDNAEU is meant to be woven into all educational environments, not only for the benefit of Native students but for increasing the cultural awareness of all students.

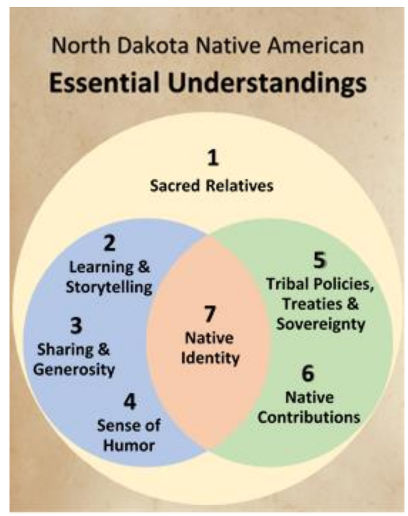

Figure 2. ND Native American Essential Understandings

We also ensured that all aspects of the project build from the strengths of the specific communities involved. An inclusive team of researchers, teachers, community members, and Elders collaboratively contributed to the elements of the teachers' PD and the engineering design tasks that build from the social, cultural, and environmental resources present in the region using an asset-based approach that has been impactful in rural North Dakota communities [44], [45]. Using the CRED framework, we supported teachers in creating engineering design tasks that aligned with content requirements and students' authentic economic, environmental, and social needs to foster a sense of self-reliance and relevance.

The PD structure is also designed to develop teacher autonomy and leadership, which has been shown to increase educator buy-in and student achievement across all contexts and **specifically in rural settings** [30]. Designing tasks to meet community needs and working in school-based teams strengthens collective efficacy and capacity for leadership in their schools. This collaborative team model allows cohorts to create cohesive and sustainable plans for implementing engineering education within their specific settings.

5. Research Design

We used a mixed methods research design to explore two main research questions (RQs):

> **RQ1:** *What is the impact of on-going, collaborative professional development on elementary and middle school teachers' self-efficacy in culturally-relevant project-based engineering instruction?*
>
> **RQ2:** *What shifts in these teachers' engineering pedagogy occur over the course of this training, and how do these shifts align with the goals of our culturally-relevant engineering professional development component?*

Study sample

The study included two cohorts of upper elementary and middle school teachers from four rural North Dakota school districts. The first cohort of 8 teachers began the program in summer 2021 and participated in two full years of PD. A second cohort of 7 teachers joined the program in summer 2022 and participated together with the first cohort for one year. The teachers taught grade levels 3-8 in subjects including science, math, social studies, and language arts. All of the schools were located in rural areas, near or on Tribal lands with significant Native American (30-100%) and low income (40-100%) student enrollments.

During Year 1 the June summer institute was held virtually due to the COVID-19 pandemic, and during Year 2 some of the teachers attended the professional development days during the school year on a rotating basis because of substitute teacher shortages.. PD sessions were recorded for those teachers that could not attend and their colleagues and the project team shared resources and ideas from the training afterwards.

Data sources

We explored the research questions using quantitative and qualitative data from several sources (Table 3), including three teacher surveys, videotaped classroom observations, teacher interviews, and focus groups.

Three teacher survey instruments, the Teaching Engineering Self-Efficacy Scale (TESS*)* [17], the amended Culturally Responsive Teaching Self-Efficacy Scale (CRTSE) [46], and a modified version of the Culturally Congruent Instruction Survey (CCIS) [47] were used. Each of the teacher surveys was administered to all participating teachers annually. Teachers took pre-surveys in the initial year of participation at the beginning of the summer before the first June PD sessions and in subsequent years in May after completing their final engineering design task for the year. The TESS survey was also administered at the end of the August PD in teachers' first summer in the program, but those results are not included in the analysis here.

Table 3. Data collection instruments

Instrument	RQ	Time administered	Sample questions or codes	Data Analysis
TESS	RQ1	Twice yearly in May/June and August	• I can recognize and appreciate the engineering concepts in all subject areas. • I can guide my students' solution development with the engineering design process	Quantitative
CRTSE	RQ1	Once yearly in May/June	• I am able to use examples that are familiar to students from diverse cultural backgrounds • I am able to help students feel like important members of the classroom	Quantitative
CCIS	RQ2	Once yearly in May/June	Frequency of use • a traditional story from a ND tribe • alternative forms of assessment like authentic assessment, or performance-based assessment • science activities in which students designed solutions to problems relevant to their community	Quantitative
modified COPED	RQ2	Three times yearly (fall, winter, spring) with classroom engineering tasks	Coded for • engineering design stage (identify, describe, embody,..) • grouping (individual - whole group) • Teacher/student focus (teacher-driven, student-directed) • culturally relevant components	Quantitative Qualitative, thematic analysis
Teacher Interviews	RQ1 RQ2	Three times yearly (fall, winter, spring) after classroom engineering tasks	• To what extent do you feel confident implementing culturally relevant engineering lessons in your classroom? • How effective was the PD in preparing you to design and implement culturally relevant engineering lessons? • To what extent did the collaboration across your cohort support your learning/confidence?	Qualitative, thematic analysis
Teacher Focus Group Interviews & Written Reflections	RQ1 RQ2	Five times yearly during summer and school year PD days	• What are you most proud of, what facilitated this success, what suggestions do you have for others? • What has been most challenging about teaching engineering in a culturally competent manner? • I used to…, then I…, now I…, I plan to…	Qualitative, thematic analysis

The **TESS** is a validated, quantitative instrument that uses the theoretical underpinnings of Bandura's guidelines to create self-efficacy scales [48] that focus specifically on elements of teaching engineering. The survey contains 23 questions that address four self-efficacy factors: pedagogical content knowledge, engagement, disciplinary, and outcome expectancy.

The amended **CRTSE** is a validated, quantitative instrument with 22 items that focus on self-efficacy across five dimensions of culturally responsive teaching: cultural strengths, school/parent relationship, culturally responsive instruction, classroom management, and standardized testing.

The **CCIS** is a 41-item, quantitative instrument that asks teachers to assess how often they incorporate various culturally congruent teaching practices in four main areas: curriculum content, instructional strategies, classroom resources availability, and additional education-related practices. The original CCIS questions were written specifically for science teachers in Montana. As recommended by the survey developers, the language was adapted for this study to reflect its use with engineering design across disciplines in a North Dakota setting.

Videotaped classroom observations of each design task were used to triangulate and supplement the data gathered through the survey instruments. In addition, we collected qualitative data through teacher interviews following each engineering design task implementation and teacher focus group interviews and reflections during the various PD sessions.

Videotaped classroom observations of teachers were collected during their administration of each of the three engineering tasks that they designed for their classrooms: one each in the fall, winter, and spring. These videotaped observations provide data on the actual changes in pedagogy reflected in teacher practice over time. An observation tool patterned after the Classroom Observation Protocol for Engineering (COPED) [49] was developed and used to quantify and describe what is occurring in the classroom. This tool includes the COPED elements for tracking engineering design stages (but adapted to the CRED stages), grouping of students, and level of teacher support, along with an additional category for measuring culturally relevant components.

Teacher interviews were conducted three times per year individually with each participant, after implementation of each engineering task. We recorded and transcribed these interviews for analysis to glean teachers' perspectives on their success with the tasks, development of their confidence and attitudes towards teaching culturally relevant engineering, and student performance. These interviews were also useful for providing input on needs for upcoming cohort meetings and provided additional context and insight on the data from survey instruments and classroom observations.

Teacher focus groups and collection of **individual written reflections** occurred during the summer PD sessions and each of the school year cohort days. We recorded and transcribed the focus groups for analysis. The teachers' responses provided data relative to both research questions, in addition to providing valuable self-reflection that helped them assess their own learning. Questions explored progress in understanding and implementing different elements of culturally relevant engineering design, identifying the most challenging aspects, and assessing the effectiveness of the PD.

Data analysis

Quantitative analysis was conducted using data from the TESS, CRTSE, and CCIS, surveys. Pre- and post-test scores for individual survey items and subscores of related items within each survey were compared to determine the magnitude and statistical significance of changes in teacher self-efficacy and classroom practice over each year of participation in the professional development program. Likert scale survey responses (e.g., strongly disagree to strongly agree) were converted to numerical values (1-6) and statistical significance was determined using the Wilcoxon Signed-Rank Test for Paired Samples. Complete paired data was available for 12 of the 15 teachers on the TESS, and for 13 teachers on the CRTSE and CCIS.

Qualitative data from the classroom observations, interviews, focus groups, and reflections are being analyzed using Braun and Clark's six-step method of thematic analysis [50]. Thematic analysis aims to derive meaning from human experiences by searching for patterns and themes in the data while acknowledging the researcher's framework imposed by existing literature [50]. Social Learning Theory [4], [7] provides a framework to contextualize the impact of the PD and the significance of the teachers' behaviors and perceptions within the research questions. The thematic analysis process is highly iterative, with codes and themes revised throughout the analysis to accurately represent the data and tell a cohesive story. In this case, a priori codes adapted from our conceptual framework, items on the modified COPED tool, and from self-efficacy theory were used to conduct the initial analysis and to create cohesion across the qualitative data sources. Initial codes included: culture, community, self-efficacy, classroom structures, engagement, and engineering design. Members of the research team independently coded a set of interview transcripts and compared coding systems for consistency and further refinement. Through the iterative process of thematic analysis, this codebook was further refined to embed the "community" code within "culture", and to add the following codes: reflection, student outcomes, and teaching self-efficacy. This process is ongoing, with coding still underway for the full set of qualitative data, and with themes from the codes beginning to emerge. Results presented here are the initial themes resulting from this coding process that have been identified relating to self-efficacy, teaching practice, and student impact.

6. Findings

A summary comparison of pre/post survey data for teachers from both cohorts is shown in Tables 4-9. Pre-surveys were administered at the start of the first summer professional development session and post surveys after one full year in the program (summer PD and full school year with PD and classroom implementation of 3 design tasks).

Table 4. Descriptive statistics of TESS pre- and post-scores from teachers participating in one year of professional development (N=12)

Subscale	Pre Mean (SD)	Post Mean (SD)	Difference	p
Content Knowledge Self-Efficacy	3.7 (1.2)	5.2 (0.5)	1.5*	0.004
Engagement Self-Efficacy	4.6 (0.8)	5.5 (0.6)	0.9*	0.010
Disciplinary Self-Efficacy	4.8 (0.8)	5.2 (0.6)	0.5	0.203
Outcome Expectancy	4.3 (0.6)	5.0 (0.7)	0.7	0.054

Pre and Post scores are mean values for all questions in each subsection. SD = standard deviation. p-values determined from Wilcoxon signed-rank test for paired samples.
*Changes are statistically significant for $p<0.05$.

Table 5. TESS items with statistically significant changes ($p<0.05$) between pre- and post-surveys for teachers participating in one year of professional development (N=12)

Section	Survey item	Change
KS	I can discuss how engineering is connected to my daily life.	1.6
KS	I can recognize and appreciate the engineering concepts in all subject areas.	1.7
KS	I can employ engineering activities in my classroom effectively.	1.6
KS	I can craft good questions about engineering for my students.	1.4
KS	I can discuss how given criteria affect the outcome of an engineering design project.	1.8
KS	I can guide my students' solution development with the engineering design process.	1.9
KS	I can gauge student comprehension of the engineering materials that I have taught.	1.4
KS	I can assess my students' engineering design products.	1.5
ES	I can promote a positive attitude toward engineering learning in my students.	0.9
ES	I can encourage my students to think critically when practicing engineering.	1.0
DS	I can control disruptive behavior in my classroom during engineering activities.	0.7
DS	I can establish a classroom management system for engineering activities.	0.8
OE	When my students do better than usual in engineering, it is often because I exerted a little extra effort.	1.3

KS = Content Knowledge Self-Efficacy, ES = Engagement Self-Efficacy, DS = Disciplinary Self-Efficacy, OE = Outcome Expectancy. Change is difference between mean score on post- and pre-survey. Survey responses converted to numerical scores: strongly disagree = 1, moderately disagree = 2, disagree slightly more than agree = 3, agree slightly more than disagree = 4, moderately agree = 5, strongly agree = 6. Statistical significance determined from Wilcoxon signed-rank test for paired samples.

On the TESS, statistically significant gains ($p<0.05$) occurred in the subscales for content knowledge self-efficacy and engagement self-efficacy (Table 4), with average gains of 1.5 and 0.8, respectively on the 6 point scale. Individual survey items on the TESS showing statistically significant changes (Table 5) are concentrated in the content knowledge self-efficacy subscale. The professional learning around the CRED framework was specifically designed to develop teacher expertise with the engineering design process, and these results indicate that the program was successful at increasing teacher self-efficacy towards understanding and using the engineering design process in their classrooms.

The CRTSE results showed statistically significant gains for the subscales regarding cultural strength (mean increase of 0.4) and standardized testing (mean increase of 1.1) (Table 6). Only two of the six individual items in the cultural strength subsection showed statistical significance (Table 7). Increases in the other four items were not large enough with our small sample size to be considered significant on their own, but taken together the six-item subscale showed growth in teacher self-efficacy around using students' cultural backgrounds to promote a more engaging, supportive, and meaningful learning experience. The gains related to identifying bias in standardized tests are interesting and may merit further investigation because that was not a topic included in any of the training we provided. Our initial assumption was that teachers had some training in this area within their schools, but follow up discussions with the teachers indicated that was not the case.

Table 6. Descriptive statistics of CRTSE pre- and post-scores from teachers participating in one year of professional development (N=13)

Subscale	**Pre Mean (SD)**	**Post Mean (SD)**	**Difference**	**p**
Cultural Strength	4.2 (0.6)	4.6 (0.5)	0.4*	0.014
School/Parent Relationships	4.4 (0.5)	4.7 (0.7)	0.3	0.151
Culturally Responsive Instruction	4.8 (0.7)	4.9 (0.7)	0.1	0.322
Classroom Management	5.0 (0.7)	5.1 (0.8)	0.2	0.383
Standardized Testing	3.5 (0.9)	4.6 (1.1)	1.1*	0.004

Pre and Post scores are mean values for all questions in each subsection. SD = standard deviation. p-values determined from Wilcoxon signed-rank test for paired samples.
*Changes are statistically significant for $p<0.05$.

Table 7. CRTSE items with statistically significant changes ($p<0.05$) between pre- and post-surveys for teachers participating in one year of professional development (N=13)

Section	**Survey item**	**Change**
CS	I am able to critically examine the curriculum to determine whether it reinforces negative cultural stereotype	0.7
CS	I am able to use examples that are familiar to students from diverse cultural backgrounds.	0.7
ST	I am able to identify ways that standardized tests may be biased towards linguistically diverse students	1.0
ST	I am able to identify ways that standardized tests may be biased towards culturally diverse students.	1.3

CS = Cultural Strength, ST = Standardized Testing. Change is difference between mean score on post- and pre-survey. Survey responses converted to numerical scores: not at all confident = 1, slightly confident = 2, somewhat confident = 3, fairly confident = 4, very confident = 5, completely confident = 6. Statistical significance determined from Wilcoxon signed-rank test for paired samples.

For the CCIS, there were no subsections that showed statistically significant changes (Table 8). This is understandable, as the survey asks about a wide variety of possible classroom activities, strategies, and practices and it was not our expectation that teachers would implement changes in all of them at once. Instead we saw that in a few areas that were a focus of the PD teachers did make notable and statistically significant changes in their teaching practice (Table 9). Resources from the NDNAEU, which were highlighted all throughout the PD, helped teachers to incorporate traditional knowledge and stories into their lesson plans. Culturally responsive practices from the CRED framework led to greater opportunities for students to assume responsibility for their learning, with authentic assessment of design solutions for problems relevant to students and their communities.

Table 8. Comparison of mean CCIS pre- and post-scores from teachers participating in one year of professional development (N=13)

Section	Pre Mean (SD)	Post Mean (SD)	Change	p
Curriculum Content	2.2 (0.6)	2.7 (0.6)	0.6	0.052
Instructional Strategies	3.4 (0.4)	3.7 (0.6)	0.3	0.191
Classroom Resources Availability	1.8 (0.7)	2.1 (0.7)	0.3	0.160
Additional Education Related Practices	2.3 (0.9)	2.3 (0.7)	0.0	0.339

Pre and Post scores are mean values for all questions in each section. SD = standard deviation. p-values determined from Wilcoxon signed-rank test for paired samples. No changes are statistically significant for $p<0.05$.

Table 9. CCIS items with statistically significant changes ($p<0.05$) between pre- and post-surveys for teachers participating in one year of professional development (N=13)

Section	Survey item	Change
CC	Used a traditional story from a North Dakota Tribe	0.9
CC	Used traditional STEM knowledge from North Dakota Tribes	0.7
IS	Encouraged students to assume responsibility for their learning - e.g., students made choices about how they studied a topic, how they were assessed, etc.	0.6
IS	Used alternative forms of assessment like authentic assessment, or performance-based assessment (instead of multiple choice, fill in the blank, e.g.)	1.0
IS	Provided ample opportunity for students to engage in private practice before publicly demonstrating their proficiency	0.8
IS	Used science activities in which students designed solutions to problems relevant to their community	2.0

CRA	Web sites or software about North Dakota Indian cultures were accessible to students	1.1
AERP	Examined your science curriculum to see how well it addresses the "North Dakota Native American Essential Understandings"	1.0

CC = Curriculum Content, IS = Instructional Strategies, CRA = Classroom Resources Availability, AERP = Additional Education Related Practices. Change is difference between mean score on post- and pre-survey. Survey responses converted to numerical scores: never = 1, seldom (1 to20%) = 2, sometimes (21-40%) = 3, often (41 to 60%) = 4, very often (61 to 80%) = 5, almost always (>80%) = 6. Statistical significance determined from Wilcoxon signed-rank test for paired samples.

Qualitative data also indicate a promising and consistent picture of increased teacher self-efficacy and changes to teaching practice. Preliminary analysis of teacher interviews, reflections, and classroom observations point to changes in self-efficacy and practice across both engineering education and culturally relevant pedagogy as summarized in the tables below.

Teacher Self-Efficacy	
Engineering	• Increased confidence, excitement, enthusiasm for implementing engineering tasks: • Intent to continue embedding engineering in future years, across content areas • Confidence with CRED framework itself • Pursuing other ways of expanding their STEM competence – conferences, coursework, etc.
Teaching Self-Efficacy	• Self-efficacy positively impacted by student engagement and excitement • Appreciate opportunity to learn alongside students • Express looking forward to implementing tasks, not feeling stress • Less reliance on scripts • More willingness to let students lead the direction of the tasks

Culture	• Increased awareness of and interest in local community, histories, cultures
	• Critically thinking about their own schooling and understanding of culturally and community situated issues/events
	• Connection to community impacts self-efficacy with engineering content – confidence with making relevant connections
	• Grappling with difference between community context/connections and embedding Indigeneity into lessons:
	  ○ What is "enough" cultural relevance to include? Is connecting to community partners and characteristics culturally relevant?
	  ○ What is the teacher's place in instructing *about* another culture?
	  ○ How to meaningfully provide opportunity for students to connect to their own lives and cultural backgrounds?

Teaching Practice	
Engineering	• Encouraging problem-solving, creativity, critical thinking in other content areas as well • Using and referencing components of CRED across content areas • More student autonomy and hands-on learning, less teacher direction and guidance • Questioning techniques that encourage student explanation and justification of thinking
Classroom structures	• Increased use of collaborative and small group work • Proximally in classroom, teachers less the center of instruction • Letting students solve own problems in other aspects of their school day
Reflection	• Using engineering teaching experiences to further refine lessons and plans for upcoming teaching • Considering their own growth in practice over time • Identifying adjustments to instructional approach • Considering students' ideas as modifications for redesign of lessons
Culture	• More intentional connection to students' lives, communities, families, cultural backgrounds embedded in instruction • More frequent engagement with community partners to enhance learning and relevance for students – field trips, guests to show real world examples of the engineering task content • Use of *Teachings of our Elders* interviews to bring Indigenous voices and perspectives to content and tasks • Seeking out resources, books, materials, stories situated in local Indigenous cultures to enhance classroom curriculum • Culturally relevant approaches more frequently observed in Identify/Describe stages of engineering design framework – fewer connections observed in Generate/Embody stages

While not a direct focus of the research, teachers also reported many positive changes with their students:

Student Impact (Teacher reported)	
Student Engagement	• Increased engagement from all students • Greatest increases in engagement shown by students who typically exhibit the least engagement, participation, and academic achievement in school • Girls in particular showing more active participation • Greater awareness and interest in local community, histories, cultures and connection to own lives

Student Outcomes	• Problem-solving, creativity, and critical thinking skills transferring to other content areas • Improved collaboration skills across content areas • Self-advocacy – students asking for more opportunity to engage in engineering, for schools to offer courses related to topics • Students who have experienced two years' of tasks build on solutions and ideas from prior year • Ability to identify and explain stages of engineering design framework (CRED) throughout tasks • Positive impact on standardized tests

Growth in teacher efficacy was well illuminated at the end of the program when we asked teachers to summarize how they had changed by contrasting what they used to do and believe, what they then did and believed, and what they now do and are planning to do in the future. A few of their comments are listed below:

> *"I used to be slightly intimidated by the engineering process & working alongside engineers. Then I collaborated with teachers, specialists to learn what questions to ask, how to design lessons, how to assess time. Now I feel confident teaching an engineering lesson. I plan to [keep using] the engineering design process. [It] uses a lot of 21st [century] skills (collaboration, problem solving communication) [that] are important skills that students will use every day in life."*

> *"I used to be hesitant in incorporating cultural pieces into my class. I didn't want to offend anyone. Then I found great cultural pieces to include in my class & resources to use. Now I am more confident in incorporating culture in my class & its importance. I plan to collaborate with teachers outside of the district and involve the community members as much as possible."*

> *"I used to have students work in collaborative groups, but felt I needed to guide and keep them together. Then I began to give them more freedom & independence. They could run their groups without me. Now I know students learn best when allowed to work independently and collaboratively. I am there to support their learning. I plan to use alternative hands-on activities allowing students to learn their best way, adapting to the student."*

> *"I started this project two years ago as an after school teacher. And now I'm finishing up a master's degree. So like, It's been huge."*

> *"Cultural relevance is now […], like, it's just an active part of me as a teacher now."*

7. Conclusions and Future Work

Study results present a consistent picture from both qualitative and quantitative data of increased teacher self-efficacy related to engineering design, teaching engineering, and cultural and community understanding. The multi-day PD model with peer mentoring and ongoing, collaborative support appears effective at changing teacher practice, not just for isolated engineering tasks, but also more broadly throughout their classrooms and across content areas.

Results also provide indirect evidence that meaningful engineering design tasks situated within the local community leads to increased student engagement for all students, as well as development of problem-solving, creativity, and collaboration skills that transfer to other content areas.

Work is ongoing to continue analysis of the collected qualitative data that will result in a more complete and refined set of codes and themes from this rich data set. This initial study involved only a small cohort of teachers and additional work is needed to confirm results with a larger study population. Future work is also planned to implement the program in other regions and demographics to demonstrate effectiveness in other settings and to determine how the PD model can be transferred meaningfully to diverse cultural communities. Other research areas include studying the persistence of shifts in teacher practice after completion of the PD program, and further exploration of the interaction between teachers' engineering teaching self-efficacy and culturally relevant teaching self-efficacy.

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