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Culturally Responsive Energy Engineering Education: Campus-Based Research Experience for Reservation and Rural Elementary Educators

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ABSTRACT: This multi-methods investigation was conducted to examine the experiences of preservice and in-service elementary teachers (n=11) from rural and American Indian Reservation communities who participated in an NSF-funded Research Experience for Teachers (RET), a summer residential research-focused professional development experience. The primary intent of the professional development was to build elementary teachers' self-efficacy in the design and implementation of community-centered and culturally responsive engineering education curricula. Over six weeks, teachers participated in energy-related research experiences in campus engineering laboratories while simultaneously developing engineering curricula for their elementary classrooms that focused on energy, a cross-cutting elementary topic. Results indicate that teachers showed significant gains in personal teaching efficacy beliefs in science and engineering. Findings also suggest that participating teachers felt significantly more comfortable teaching engineering post-program compared to pre-program. Quantitative results from this study align with the qualitative findings and indicate that the experience positively impacted teachers' capacities to teach engineering and integrate culturally responsive practices. Results also help identify specific attributes of the experience that contributed to their professional learning. Findings from this study contribute to the refinement of theories on teacher self-efficacy in engineering education and help guide future professional development efforts that foster inclusive student engineering identity formation within their classrooms.

INTRODUCTION

Despite best efforts to increase representation in the STEM workforce, underrepresentation remains a well-documented hurdle (Patel et al., 2021). A focus on inclusion will bring diversity to the problem-solving efforts afoot for addressing our nation's scientific and social challenges. However, research continues to point to a lack of diversity in STEM fields with disproportionally low representation in science and engineering compared to the U.S. population (National Science Foundation, 2021). Traditionally underrepresented populations continue to report challenges and lacking a sense of identity and belonging in STEM careers (Patel et al., 2021). Social, cultural and gendered norms, as well as the absence of role models and mentors can challenge engineering identity formation, especially in young female students (National Academy of Engineering, 2014; National Science Foundation, 2021) and underrepresented students, including those who are Indigenous. For example, girls start to lose interest in engineering around the age of twelve (American Association of University Women Educational Foundation, 2000), with middle school serving as a critical point in developing female-identifying STEM identity (Hughes et al., 2020). Perceived mismatches between an individual's culture and their perceptions of engineering can inhibit interest in engineering (Davis and Finelli, 2007). This is particularly true for Indigenous students who report not seeing how engineering can help reservation communities (Kant et al., 2015). Further, students who do not form an engineering identity at an early age tend to not pursue engineering (American Association of University Women Educational Foundation, 2000). However, viable solutions for addressing these disparities do exist, such as early interventions in students' STEM identity formation.

Building young learners' STEM identity presents unique challenges when teachers' preparation and readiness to teach

STEM effectively is examined. These issues are magnified at the elementary level where initial STEM identity formation is so important. Research indicates elementary educators rarely possess specialized STEM degrees or take engineering courses in college. Few report that they have received professional development in engineering, leaving them lacking in self-efficacy in this area of STEM instruction (Banilower, 2018). Given the pressing need to integrate early interventions to build elementary learners' STEM identity and interest prior to middle school when many lose interest, teacher educators should reconsider engineering education professional development for elementary teachers. Consequently, the purpose of this NSF-funded Research Experience for Teachers (RET) titled "Culturally Responsive Energy Engineering Education in Rural/Reservation Elementary Schools" was to provide elementary teachers opportunities to build their engineering self-efficacy and facilitate the development of culturally responsive engineering education curricula targeted for rural and Indigenous contexts.

Current State of Engineering Education in Elementary Context. Science, technology, engineering and mathematics (STEM) are interwoven throughout everyday life, necessitating that all citizens have a basic level of STEM literacy in order to make informed decisions about such topics as health care, energy efficiency, and resource usage (National Academies of Sciences Engineering and Medicine, 2020). STEM literacy is of such importance that national reform initiatives are focused on the development of education standards that will promote STEM literacy for all K-12 students. *A Framework for K-12 Science Education* and the resulting Next Generation Science Standards (NGSS) are one example of these latest reform initiatives (National Research Council, 2012; NGSS Lead States, 2013). Because the NGSS have "the potential to be inclusive of students who have been traditionally marginalized in the science classroom" (NGSS Lead States, 2013, p. 13), these standards have the potential to reduce achievement gaps seen between different groups of students (Breton, 2017).

Despite the intent of NGSS to advance engineering education in the US, many teachers, particularly those at the elementary level, lack confidence in their abilities to teach engineering (Hammack and Ivey, 2017) with most not taking an engineering course in college (Banilower, 2018). Among elementary teachers, more than half say they are not adequately prepared to teach engineering, and only about a quarter say they feel prepared to encourage students' interest in science and/or engineering. And fewer than a third of all K-12 science teachers have attended professional development on deepening their understanding of engineering or engineering principles (Banilower, 2018). All this leads to the importance of enculturing self-efficacy of elementary teachers while offering them the tools and professional training to simultaneously teach, encourage students to appreciate, understand, and perhaps identify with engineering.

Engineering Teaching Efficacy. Teaching effectiveness is linked to teaching efficacy, as teachers who have higher levels of teaching efficacy are more successful in the classroom (Cakiroglu et al., 2012). Teaching efficacy refers to a teacher's belief in their ability to influence student learning (Guskey and Passaro, 1994), which is an extension of Bandura's theory of self-efficacy (Bandura, 1977). Teaching efficacy is dependent upon context (e.g., grade level, content areas) and various instruments have been developed to measure teaching efficacy in specific disciplines such as mathematics (Enochs et al., 2000), science (Enochs et al., 1993), and more recently, engineering (Yoon et al., 2014). With these instruments and others, researchers have found that teachers felt they lacked the pedagogical content knowledge (PCK) necessary to teach engineering in a way that would have meaningful outcomes for their students (Hammack and Ivey, 2017).

Other studies have reported that participating in engineering professional development opportunities has a positive impact on the engineering teaching efficacy of preservice teachers (Fogg-Rogers et al., 2017; Perkins Coppola, 2019; Smetana et al., 2019) and in-service teachers (Crawford et al., 2021; Utley et al., 2019). Further, preservice teachers who engaged in multiple engineering learning activities within a K-8 science methods course, have significantly higher engineering teaching efficacy and outcome expectancy than prior to engaging in the course (Hammack and Yeter, 2022).

Teacher Professional Development. Because elementary teachers have reported limited experience (Banilower et al., 2018), and low teaching efficacy (Hammack and Ivey, 2017) in engineering, providing them with high-quality professional learning opportunities is essential to shift instructional practices. This includes engineering design as required by NGSS (Britton et al., 2020; Nilsen et al., 2020). Indeed, numerous studies support the use of engineering-focused professional development to enhance teachers' engineering content knowledge and understanding of engineering design (Duncan et al., 2011; Guzey et al., 2014; Utley et al., 2019; Yoon et al., 2013).

Mesutoglu and Baran (2021) suggest several research-based guidelines for the design of effective engineering professional development to include: (1) use a variety of instructional methods such as presentations, panels, field trips, and hands-on activities; (2) provide teachers opportunities to work collaboratively with other teachers, engineers, and researchers; and (3) provide ongoing constructive feedback. The design of such research-based engineering professional development efforts can be facilitated through The National Science Foundation's (NSF) Research Experience for Teachers (RET) program (National Science Foundation, 2023). The RET program provides funding for K-14 educators to engage in authentic hands-on research experiences and build long-term collaborative relationships with research faculty and industry mentors. Research on RETs suggest that these experiences provide reciprocal benefits to both participating teachers and university research mentors (MacFadden et al., 2022), help teachers build their confidence and efficacy in teaching engineering (Schneider et al., 2020; Thomson and Turner, 2019), and provide opportunities to connect disciplinary knowledge and practice to pedagogical strategies (Wakefield, 2022). Further, research on RETs suggests that the experiences can build teachers' understandings of effective engineering instructional practices (Bowen et al., 2021; Thomson and Turner, 2019). While many RETs focus on building their cohorts with a combination of elementary, middle, and high school educators (Lichtenstein and Phillips, 2021; MacFadden et al., 2022; Saka, 2013; Schneider et al., 2020; Thomson and Turner, 2019; Wakefield, 2022), a search of current and past RETs suggests that few focus entirely on elementary educators. Consequently, we consider the emphasis of our RET on elementary grade teachers, where all participating educators taught or planned to teach in elementary contexts, a hallmark of our program.

Purpose of the Study. This multi-methods study examines the experiences of preservice and in-service elementary teachers from rural and American Indian Reservation communities who participated in a summer residential research professional development experience focused on energy concepts in engineering education. Considering that previous research indicates elementary teachers report little experience in engineering and low efficacy in engineering education (Hammack and Ivey, 2017), we wanted to better understand how providing high-quality professional development might influence participants' engineering self-efficacy. Additionally, we wanted to better understand what attributes of the program contribute to the participants' professional development.

We used the following research questions to guide our inquiry: (1) How does participation in a summer engineering-focused research experience with accompanying culturally responsive professional development affect teachers' self-efficacy? (2) What attributes of the summer research program do teachers report contribute to their teaching practice?

METHODS

The overarching goals for the summer RET included efforts to (1) promote inclusive engineering identity formation among diverse rural and reservation students by (2) increasing elementary teacher self-efficacy in culturally responsive engineering education via (3) establishing a collaborative ecosystem among regional elementary schools, industry and academia focused on energy research and diversifying the future engineering workforce.

To achieve our primary goals, the program facilitated an engaging, holistic, and integrated six-week summer research experience for teachers (RET). We coupled laboratory experiences with customized, guided, and reflective field trips to energy industry facilities and nearby cultural venues. In terms of integration, we structured the professional development to afford opportunities for the teachers to work collaboratively on combining and sharing unique and high-impact energy-related engineering curricula in their diverse elementary classrooms.

Participant Recruitment and Selection Criteria. Our team began the recruitment process with some concern that we would not receive adequate applications and might need to adjust our application deadline, or reconsider our selection criteria. Recruitment concerns were ultimately unfounded, though, and interest in the program exceeded expectations. This was likely due to marketing the summer RET across the state. Our team publicized the research experience through statewide professional organizations focusing on those representing small rural schools. To attract preservice teachers, we requested that teacher education faculty advertise the research experience in their courses, and we publicized through our teacher education student group. These tactics ultimately resulted in a pool of high-quality applicants.

Once the application deadline closed, we narrowed the pool to those applicants meeting two primary criteria: (1) Applicants were to be teaching, or preparing to teach, in upper elementary grades, and in particular, grades 3-5; (2) Applicants were teaching, or planned to teach, in rural, reservation or otherwise under-served districts in our state. The decision to keep the grade band in upper elementary was rooted in the research on STEM interest and identity development. As delineated above, the research indicates that many students tend to lose interest in STEM in the middle school grades, and a primary intent of this study was to build elementary teachers' self-efficacy in engineering education. Secondly, we rooted our selection criteria in the research on underrepresentation in STEM. Indigenous peoples remain "severely underrepresented" when it comes to diversity in STEM (National Science Foundation, 2021). As a result, and to build interest in STEM in underserved and Indigenous communities, we required that applicants be currently teaching, or committed to teach, in a rural, reservation or otherwise underserved district in our state where the largest underrepresented subgroup of students are identified as Indigenous.

Participants. Ultimately, eleven teachers were invited to participate in the first year of the program. Seven of the participants were in-service teachers, and four of the participants were pre-service teachers enrolled in the university's elementary education program. Table 1 provides demographic data about the final eleven participants.

Once selected, participants were eligible for a financial stipend as well as support for materials for their classroom. Teachers were awarded $6000 each for participating, and were given travel reimbursements including mileage and meals. In addition, if they chose to be residential participants living on campus, their room, board, and parking were covered. Those participants who did not live in the vicinity of the university received support for daily mileage expenses and campus parking passes. Additionally, participants were granted free registration to a three-day STEM Summer Institute (SSI) professional development conference held in August, a year-long membership to either the Montana Science Teacher Association (for the in-service teachers) or university Aspiring Educators Club (for the pre-service teachers), and would be eligible for up to $500 worth of classroom supplies to support the lessons they created following the RET. And lastly, teachers were also awarded graduate credit and continuing education units for their participation in the program.

As shared, university housing was provided throughout the six-week period, and most participants took advantage of this affordance. However, those teachers who were local to the university drove back and forth each day from their homes to campus. For those that made use of the room and board benefits, proximity allowed some to travel home on the weekends, while the geographic vastness of Montana made this prohibitive for others.

Table 1. *RET Participant Demographics.*

Gender	n
Man	2
Woman	9
Prefer not to say	0
Race/Ethnicity	
American Indian or Alaska Native	3
Native Hawaiian or other Pacific Islander	1
White	7
Prefer not to say	0
Age	
18-22	3
23-25	4
36-45	2
46 and older	2
Professional Status	
Pre-service Teacher	4
In-service Teacher	7
Teaching Context for In-Service Teachers (*n*=7)	
Reservation/Reservation Border School	2
Rural School	4
Other	1
Years Teaching Experience	
< 1 year	4
1-5 years	3
6-10 years	1
> 11 years	1
Prefer not to answer	2
Grade Level for In-Service Teachers (*n*=7)	
2nd/3rd Combined	1
3rd	2
5th	3
Multigrade (1st – 8th)	1

Context. The RET took place at a large land-grant university located in the Northern Rocky Mountains with a student population of over 16,000. The university is currently ranked as "very high research activity" under the Carnegie Classification of Institutions, with over $200 million in research expenditures in fiscal year 2022. The university also has engineering research institutes, an engineering education research center, and a STEM education resource center. Further, the university has a long-standing culture of interdisciplinary collaboration across departments, colleges, and centers. The research team leveraged these already-existing partnerships to provide participants with comprehensive support from the university's college of engineering and department of education.

Summer Research Experience Components.

Program Structure and Professional Development Offerings. The RET formally launched in June 2022. The teachers spent roughly three full days each week in the research laboratories working with host researchers. One day each week was focused to field trips to cultural and industry tours and experiential learning. And one day per week was focused on providing teachers time for reflection and group work. No formal evening sessions were planned for RET participants, and instead, that time was left open for them to plan on their own. Because evening sessions were not scheduled, participants often organized their own social activities like trips to the local farmer's market, beading circles, hiking, and eating at local restaurants. Table 2 provides an overview of the time distribution for each of these activities.

In the first week of the program, the research team provided participants a formal orientation, initial workshops on the curricular components, and two-way knowledge exchange opportunities. Another key component of the orientation process was pairing participants with research mentors. Participants were introduced to possible laboratory placements and mentors through tours, presentations and introductions.

Table 2. *Weekly Time Distribution for RET Components.*

Day of Week	Monday	Tuesday	Wednesday	Thursday	Friday
RET Component	Lab work	Lab work	Lab work	Field trips, experiential learning	Reflection and group work
Percentage of Time Allotted Per Week		60%		20%	20%

The participants then rank-ordered those labs, indicating labs in which they would most like to work. Following the orientation and rank-ordering process, the research team paired participants with the engineering research mentors.

The professional development sessions also were formally launched in the first week of the RET. The sessions had two primary foci: (1) Content-specific and research professional development; and (2) Curriculum-specific professional development. The content-specific and research professional development took place within the energy-related research laboratories. In those laboratories and through working with the research mentors, participants began the hands-on energy-related research. Their participation in those research laboratories contributed directly to funded research projects such as building energy systems, biomass energy conversions, fluid flow processes, materials for energy conversion technologies, and sustainable transportation systems. Further, each laboratory experience was designed intentionally to afford participants the opportunity to design and conduct experiments, make measurements, and analyze data in support of active research projects.

Curriculum-specific professional development occurred throughout the entire six-week experience and focused on the following components: Next Generation Science Standards (NGSS); BSCS 5E model for instructional design (Bybee, 2014); Indian Education for All (IEFA), a curricular framework and Montana state law used to identify essential understandings about the culture and history of American Indians (Starnes, 2006) and focused on preserving the cultural integrity of each Montana tribe; Indigenous science knowledge (ISK), or the unique traditional environmental and cultural knowledge specific to a particular people that emphasizes context, interdependence and relational connections (Cajete, 2020); and lastly, the universal design for learning (UDL) framework, the neuroscience/cognitive science-based framework that can be used to improve and optimize teaching and learning for all people based on scientific insights into how humans learn (Hall et al., 2012). The research team used a learning management system course to provide participants access to professional development modules.

The first component of the curriculum-specific development focused on NGSS and the 5E instructional model (Bybee, 2014). The research team worked with participants on how to unpack the NGSS to identify the knowledge and skills students should acquire for each standard. Teachers completed two online self-guided courses that addressed the 3D nature of NGSS and included a substantive review of the Science and Engineering Practices (SEPs) and teaching with phenomenon. Subsequently, the research team supported the participants as they navigated a backwards design approach to develop an NGSS-aligned 5E lesson based on the content they were researching in their assigned laboratories. The backwards design approach to curriculum development involves first identifying the desired end goal or performance expectation a teacher wants their students to be able to complete. The 5E approach focuses on inquiry-based instruction and has been found to be an effective model for teachers to incorporate the three dimensions of NGSS (Bybee, 2014). At this stage, teachers identified the content knowledge and skills necessary for students to complete the desired performance expectation. Next, teachers identified evidence that would indicate student mastery of the content and skills. Finally, teachers developed a set of instructional activities to scaffold student development of the requisite knowledge and skills.

A second component of the curriculum-specific professional development was on engineering education. The engineering design process used with the engineering education activities was modeled after the Engineering is Elementary curriculum (Cunningham, 2009; Lachapelle et al., 2011). For example, participants engaged in a tower building activity that emphasized a place-based engineering design task associated with our local museum. Participants were then prompted to reflect on what actions they engaged in during the tower building activity, and then that brainstorming session was used to construct their engineering designing process. Engineering education professional development also included a three-hour session where participants experienced a solar-cooker design task that contained cultural connections.

Curriculum-specific professional development also focused on developing participants' understanding of and integration strategies for IEFA and ISK. Participants were introduced to the IEFA essential understandings and how to use them to frame instructional design of their lessons. Another key emphasis in the professional development was developing deeper understanding of ISK tenets and how ISK can be integrated into the participants' teaching and their students' learning. Participants engaged in research-informed activities to help build cultural awareness and knowledge of Indigenous wisdom and engineering practices, such as tipi raising, hide tanning and food preparation, and how this wisdom and these practices relate to energy and engineering.

A final component of the curriculum-specific professional development was on UDL. More specifically, at the start of the experience, participants explored how to use UDL to structure best-practice accessible instructional design of their resulting engineering curriculum. Most importantly, participants explored how UDL emphasizes inclusivity. It is about honoring and connecting to the culture, background, and neurology of students. Therefore, use of the UDL framework aligns strongly with IEFA and with the culturally responsive nature of the proposed project.

Overall, the total professional development sequence included weekly milestones. By the end of week 2, the research team worked with teachers to identify appropriate NGSS standards that align with the research they would be completing in their assigned lab. During weeks 3 and 4, teachers identified a final student performance expectation and learning objectives for those performance expectations. In weeks 4 and 5, teachers utilized the multiple frameworks to which they were introduced to develop the instructional sequence their students would complete. In total, this included using backwards design and framing their lesson development with the 5 E approach, making purposeful and sound connections to IEFA and ISK, and aligning the entire curriculum in UDL principles. The professional development work concluded during week 6, when teachers shared their laboratory research experiences and draft lesson plans with other participants, research mentors, industry advisory board members, and fellow teachers during a local summer science institute for K-12 STEM educators.

Faculty and Research Mentors. In total, six engineering faculty, three within chemical and biological engineering, one within civil and environmental engineering, and one within mechanical and industrial engineering, served as research mentors for RET participants. Those host researchers were assisted by respective teams of post-doc, graduate, and undergraduate students that routinely interacted with the participating teachers. The focus of the research mentors' laboratories, and consequently, the focus of the summer participants' research and curriculum development were water filtration, high-temperature chemical processing and energy conversion systems, the impact of load and aging on bone remodeling, biofuels made from algae, HVAC systems, and byproducts of biorefineries.

In advance of the program, research mentors were provided support and training to prepare them to work alongside the participating teachers. First, the mentors were given guiding documentation that included a set of expectations to structure the research experience for the teachers. Host researchers were also provided a stipend of up to $2000 per teacher for reimbursement of laboratory supplies. In terms of formal training, the research mentors were required to complete a series of university-developed training modules that focused on IEFA, Responsible Conduct of Research (RCR), and Title IX mandatory reporting. In addition to these training modules, each research mentor met with the project's PIs to contextualize elementary STEM learning and strategies for working collaboratively with elementary teachers. Anecdotally, the PI of the project shared that these one-on-one meetings were the most "high impact" trainings the research mentors received in advance of the RET launching.

There was considerable diversity in the expectations the mentors had regarding teachers' design and implementation of experiments. Some mentors assumed the RET participants would be engaged in laboratory research from start to finish, while other mentors assumed participants would assist with certain elements of their research agenda like data collection or data analysis. Each research mentor required different trainings and on-ramping experiences from the teachers in their labs, yet each mentor committed to providing all teachers rich, authentic, hands-on laboratory experiences.

Industry Advisory Board. An Industry Advisory Board (IAB) comprised of engineering alumni from the university, provided recommendations to the project team on program design and workforce needs. The IAB helped host guided tours of industry-scale energy facilities and assist participant teachers with curriculum development and classroom integration. IAB members included an Indigenous engineer working in the energy industry, a female chemical engineering alumna also working in the energy industry, a mechanical engineer alumnus working in solar energy, a chemical engineer whose work focuses on STEM-based educational technology resources, and an engineering alumnus who focuses on sustainability initiatives and solar energy.

Industry Facilities and Cultural Field Trips. A key feature of the research experience was the field trips to energy-related industry sites, including a visit to a hydroelectric dam that was facilitated by engineering alumnus. Another unique and integral feature of the RET was customized, expert-guided, and research-informed tours of regionally co-located venues with local Indigenous cultural significance. Most notably, this included visiting a local buffalo jump (Doyle, 2012), a cliff formation which Indigenous peoples of North America historically used to hunt and kill plains bison. This visit was facilitated by a local expert in Indigenous culture and history.

In addition, participants were given the opportunity to engage in on-campus tours that connect to the research experience like viewing the geothermal energy district that runs below campus and distributes heat among these buildings for optimal efficiency. Participants were also among the first campus visitors to interact with a newly constructed American Indian building on campus, which in addition to its state-of-the-art geothermal and solar power systems and energy efficiency design, hosted interactive learning opportunities for participants to engage with local Indigenous culture.

RET Deliverables. At the conclusion of the RET, teachers developed a 5E learning sequence that they could implement in their classrooms, as well as a variety of artifacts representative of their curriculum development efforts during the six-week experience. For example, one Indigenous teacher from a reservation school and community was embedded within a material sciences laboratory for his RET. Through integrated specialized microscopy training coupled with conversations with cultural experts, he developed a lesson for his students on brain tanning of hides. This is an appropriate example of how the teachers developed diverse curricular integrations based on their unique laboratory research experiences and interests, integrated what was learned from the professional development modules on NGSS, 5E, ISK, IEFA, and UDL, and developed learning sequences tailored to their teaching contexts and students. Again, it should be noted that school year implementation of the learning sequence was encouraged, but not required. Therefore, the delivery of the learning sequence was outside the scope of the project and this study.

DATA COLLECTION

This multi-methods investigation was conducted to respond to our research questions that address participants' experiences during the summer engineering-focused research program and the effects on teachers' self-efficacy, as well as the program characteristics that contributed to their professional development. Quantitative data were collected in a pre/post design with the T-STEM survey, which measures teacher efficacy and beliefs for teaching STEM. Qualitative data were collected from post-program focus groups.

The T-STEM survey is a collection of surveys developed by researchers at the William and Ida Friday Institute for Educational Innovation (2012). The instruments were developed to measure teacher efficacy and beliefs for teaching STEM. There are four versions of the instrument, three of which were used in the current survey: engineering, mathematics, and science. The T-STEM originally consisted of 20 items, 11 of which measured Personal Science Teaching Efficacy Beliefs (PSTEB) and 9 that measured Science Teaching Outcome Expectancy Beliefs (STOEB). However, subsequent Rasch analysis and confirmatory factor analysis (Unfried et al., 2022) with a sample of 718 teachers indicated that a three factor solution accounted for the greatest amount of variability in the data. The items measuring STOEB have been divided into two groups, denoted as STOEB1 and STOEB2. STOEB1 is focused on above-average student interest or performance, and STOEB2 is focused on neutral or below-average student interest or performance. In addition, the 11 items measuring PSTEB have been reduced to 9. The T-STEM administered to teachers this summer contained 54 items (18 each for engineering, science, and mathematics) measured on a 5-point Likert scale ranging from a 1 being "Strongly Disagree" to a 5 being "Strongly Agree".

In terms of qualitative data, the research team scheduled a post-program focus group with participants. The focus group was remotely facilitated by an external evaluator. No members of the research team were present during the focus group, and results were de-identified prior to the external evaluator sharing findings with the research team. The focus group facilitator guided the conversation to emphasize the positive outcomes of the summer research program, concerns or issues experienced during the summer research program, and recommendations for future cohorts.

RESULTS

Results from both the quantitative measures and qualitative measures are provided below. For the quantitative findings from the T-STEM survey, results are reported for the Personal Science Teaching Efficacy Beliefs (PSTEB) and Science Teaching Outcome Expectancy Beliefs (STOEB) components. For the qualitative findings, results are reported for the post-program focus group.

Descriptive statistics for PSTEB, STOEB1, and STOEB 2 organized by content area are presented in Table 3. The PSTEB measures a teacher's personal teaching efficacy beliefs in science, mathematics, and science, with higher scores indicating higher teacher efficacy beliefs. For PSTEB, descriptive statistics were calculated on the teachers' combined responses across items 1, 2, 3, 4, 6, 8, 9, 10, and 11 on the PSTEB for each of the three curricular areas, both pre- and post-summer program. Items 5 and 7 were eliminated. The STOEB1 measures a teacher's "teaching outcome expectancy beliefs," with this subsection focusing on above-average student interest or performance. For STOEB1, descriptive statistics were calculated for both pre- and post-surveys on teachers' combined responses across items 1, 3, 7, and 8 for each of the three curricular areas. Higher scores indicate higher outcome expectancy beliefs. The STOEB2 measures "teaching outcome expectancy beliefs" for neutral/below-average student interest or performance. For STOEB 2, descriptive statistics were calculated for both pre- and post-surveys on teachers' combined responses across items 2, 4, 5, 6, and 9 for each of the three content areas. Higher scores indicate higher outcome expectancy beliefs.

Inferential Statistics on PSTEB, STOEBI, AND STOEB2.

To analyze whether statistical differences occurred between pre/post scores for the science, mathematics, and engineering portions of the survey, a multivariate, repeated measures analysis of variance (RM-ANOVA) was conducted for each content area. The repeated measures in the analyses for each section of the survey were PSTEB, STOEB1, and STOEB2. The dependent variables were pre- and post-test mean scores on each of the three measures for each content area. Keep in

Table 3. *Personal Science Teaching Efficacy Beliefs (PSTEB), Science Teaching Outcome Expectancy Beliefs (STOEB).*

Science					
PSTEB Science		**Mean**	**SD**	**Min**	**Max**
	pre	3.78	(.53)	2.67	4.46
	post	4.26*	(.43)	3.56	5.00
STOEB1 Science		**Mean**	**SD**	**Min**	**Max**
above average	pre	3.61	(.45)	2.75	4.25
	post	3.91*	(.64)	3.00	4.75
STOEB2 Science		**Mean**	**SD**	**Min**	**Max**
neutral/below average	pre	3.71	(.62)	2.60	5.00
	post	3.84	(.79)	2.20	5.00
Mathematics					
PSTEB Mathematics		**Mean**	**SD**	**Min**	**Max**
	pre	4.10	(.41)	3.67	5.00
	post	4.42*	(.34)	3.89	5.00
STOEB1 Mathematics		**Mean**	**SD**	**Min**	**Max**
above average	pre	3.75	(.81)	2.25	5.00
	post	3.86	(.74)	2.50	4.75
STOEB2 Mathematics		**Mean**	**SD**	**Min**	**Max**
neutral/below average	pre	3.73	(.75)	2.60	5.00
	post	3.82	(.75)	2.20	4.80
Engineering					
PSTEB Engineering		**Mean**	**SD**	**Min**	**Max**
	pre	3.38	(.59)	2.44	4.22
	post	4.30*	(.49)	3.44	5.00
STOEB1 Engineering		**Mean**	**SD**	**Min**	**Max**
above average	pre	3.77	(.60)	3.00	5.00
	post	3.91	(.66)	3.00	5.00
STOEB2 Engineering		**Mean**	**SD**	**Min**	**Max**
neutral/below average	pre	3.69	(.64)	2.60	5.00
	post	3.82	(.79)	2.20	5.00

* *Indicates significant differences*

mind that for each inferential test conducted, the small n (11) limits statistical power, and the lack of an effect may be due to this small n.

Science. Results from the inferential statistics on PSTEB, STOEBI, AND STOEB2 indicate that the multivariate, within-subjects effects for science were significant, Wilks' Lambda = .28, $F(3, 8) = 7.03$, $p = .012$, partial eta squared ($\eta^2 p$) = .725, a large effect size. For PSTEB, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-PSTEB scores was significant with a large effect size, $F(1, 10) = 18.61$, $p = .002$, $\eta^2_p = .65$. For STOEB1, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB1 scores was significant with a large effect size, $F(1, 10) = 7.82$, $p = .019$, $\eta^2_p = .44$. For STOEB2, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB2 was not significant, $F(1, 10) = .26$, $p = .62$, $\eta^2_p = .02$.

Mathematics. On each of the three measures for mathematics, the multivariate, within-subjects effects were not significant, Wilks' Lambda = .63, $F(3, 8) = 1.56$, $p = .272$, partial eta squared (η^2_p) = .37. For PSTEB, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-PSTEB just reached significance, $F(1, 10) = 5.20$, $p = .046$, $\eta^2_p = .34$. For STOEB1, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB1 was not significant, $F(1, 10) = .35$, $p = .567$, $\eta^2_p = .03$. For STOEB2, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB2 was not significant, $F(1, 10) = .16$, $p = .702$, $\eta^2_p = .02$.

Engineering. Last, for engineering, the multivariate, within-subjects effects were significant with a large effect size, Wilks' Lambda = .308, $F(3, 8) = 5.98$, $p = .019$, partial eta squared (η^2_p) = .69.

For PSTEB, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-PSTEB was significant with a large effect size, $F(1, 10) = 4.65$, $p = .001$, $\eta^2_p = .69$. For STOEB1, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB1 was not significant, $F(1, 10) = 1.00$, $p = .341$, $\eta^2_p = .09$. For STOEB2, the follow-up univariate test using the Greenhouse-Geisser correction indicated that the difference between pre- and post-STOEB2 was not significant, $F(1, 10) = .25$, $p = .626$, $\eta^2_p = .03$.

PSTEB, STOEB1, and STOEB1 Summary from All Three Content Areas. Across all the three sub-sections (PSTEB, STOEB1, and STOEB1) and across the three content areas assessed by the T-STEM (science, mathematics, and engineering), teachers' responses ranged approximately in the 3-to-4 range, Neither Agree or Disagree (3) to Agree (4). There were significant gains in the science and engineering post-survey scores on the PSTEB, with large effect sizes for science and engineering (.65 and .69, respectively). For mathematics, the post-survey score on the PSTEB showed a significant gain; however, because the multivariate test was not significant, this significant gain is questionable. It should be noted that there were additional survey items on the T-STEM used to examine participants' comfort teaching engineering, general integration of educational technology, engagement of students in critical thinking, values placed on student learning, teacher ownership of student learning, and lastly, teachers' knowledge of STEM. The research team did collect and analyze those data, but agreed results were not germane to this specific study for a variety of reasons.

Post-Program Focus Group Results. The qualitative data source in this multi-methods study was a post-program focus group conducted with all 11 participants during the final week of the research experience. The external evaluator facilitated the focus group, transcribed the meeting, and shared the de-identified transcript with the research team at the conclusion of the RET. While focus groups allow for the collection of perspectives from greater numbers of participants in a shorter time period, the choice of a focus group was also important for us to "capitalize on the richness and complexity of group dynamics" (Kamberelis and Dimitriadis, 2005, p. 903) and explore the professional relationships that developed during the program. Further, participating in focus groups can help "to build a stronger and more effective collective" while generating data that might not otherwise exist due to the mobilization of "the collective energy of the group" (Kamberelis and Dimitriadis, 2005, p. 900).

Transcript data from the post-program focus group were carefully examined and coded using the six-step thematic analysis process described by Braun and Clark (2012). As suggested by Braun and Clark, we did not "clean up" the transcript, choosing instead to keep participant language intact. Throughout the entirety of data analysis, we wrote analytic memos and kept an audit trail to document the details of the process. Our data analysis process consisted of the following steps: (1) carefully reading the transcript to familiarize ourselves with the data, (2) engaging in an initial round of descriptive coding (Saldaña, 2021), (3) searching for patterns in the codes to construct themes, (4) reviewing, revising, and eliminating potential themes based on their fit with the entire data set, (5) finalizing and defining the resulting themes, and (6) reporting the findings.

Data from the qualitative analysis yielded several key themes centered around (1) Program Successes; (2) Program Concerns; and (3) Recommendations for Future Cohorts. The "Program Successes" theme included attributes and characteristics of the RET that participants reported led to the success of the program and impact on their teaching practice. The "Program Concerns" theme included those attributes and characteristics of the RET that participants reported as prohibitive factors in the program's success and influence on their practice. And lastly, the "Recommendations for Future Cohorts" included findings that focus on what participants recommend the research team consider for ensuring the success of the program for future cohorts.

Program Successes. Analysis of focus group data indicate that participants' reflections and perceptions about their experiences are largely positive and corroborate quantitative findings about the influence of the program on participants' professional development. Consequently, the "Program Successes" theme emerged that includes those characteristics that research program participants saw as successes and contributing in a positive way to their professional growth. First, participants reported that "Collaboration" was a critical component of the program that supported their professional development. Further, participants shared that the "collaboration" took many different shapes throughout the experience, from the formal collaborations with the research mentors, collaborations between the pre-service and in-service teachers, and working with the research team. One participant highlighted the "investment" that a research mentor put into their time together. That participant reported, "So he really put in the time to make it worth our while," and "... he was invested in the process and he was invested in us." Participants also shared that it was the conversations, both formal and informal, that drove those collaborations and led to their professional growth. For example, participants reported that the informal conversations with one another during meals, and the "hallway talk," were invaluable components of the program. One participant stated that it was, "the gab time at lunch and our walks and the dorms in the evening" that helped build rapport and connection among the participants.

This collaborative spirit was clearly instrumental in establishing the groundwork needed for them to create their own professional learning community built upon respect. One participant shared, "It's all mutual respect. From the academics down to the pre-service teachers, there was an equal level of respect and mutual appreciation for each other." Each week the cohort and research team members would meet to debrief over the week and reflect on topics ranging from sustainable energy to systematic barriers faced by underrepresented groups. Indigenous participants and those teaching in reservation border towns frequently shared about their lived experiences teaching within those cultural contexts, and many white participants spoke about lack of self-efficacy and confidence with IEFA due to a fear of not teaching it correctly. Creating a safe space where participants felt respected and valued, and where they could be vulnerable to discuss sometimes tough, emotionally heavy topics, was vital.

Participants also reported that the program's on-campus housing further contributed to establishing a sense of community among the group. As a research team, we recognized how hard it is for teachers to be away from their families for extended periods of time and felt allowing them to bring their families to campus for the research experience would support not only recruitment but retention of the participants. In turn, it was validating from a program design perspective to hear how participants appreciated this feature, and that some took advantage of the offer to bring their families with them. Coincidentally, those participants that did not choose to live on campus during the experience recognized that they were missing out on those after-dinner conversations and engagement with the cohort. One participant who did not live on campus shared, “[The research experience] was valuable, life changing. But staying here [on campus], being together, those conversations happen at the evening.”

Participants also reported that the emphasis on building cultural connections between their lab work and the design of their lessons was critical to their professional growth and the program’s success. The dedicated time to address IEFA and ISK provided many in the cohort an opportunity to explore those frameworks with depth and substance in ways that they would not have done otherwise. One participant reported, “I imagine this will have a significant impact on just how I approach IEFA in general in all subjects and not just science, but then the engineering aspect as well.”

Others indicated that the reflection time provided each week played a central role in helping them establish a deeper sense of how the program affected their practice. Participants were provided prompts to encourage reflection about what they were learning in their labs, the research process in general, cultural connections, and engineering. One participant shared that the “time for reflection has probably been the most influential for me even above a lot of the formal stuff.”

Program Concerns. Analysis of focus group data also resulted in the “Program Concerns” theme that represents those characteristics of the research program that participants saw as prohibiting their professional development during the RET. The primary concern reported by participants were issues with the research mentors and research focus in the labs. Some participants shared that although they appreciated the efforts made to appropriately match mentors and teachers through the rank ordering of choices, not being able to directly pick the lab in which they were placed made it more challenging for the participants to align their research with their classroom practice or content. One participant was placed in a lab engaged in early-stage research, and the teacher reported that the exploratory nature of the research in that lab often felt too vague and without direction. The participant shared, “[The mentor] didn’t really know where she was going with her research either. She had an end goal, but it was still early on in her what she was doing.” Other participants shared that despite their enthusiasm for the research process, their lack of experience with the technical equipment in the lab and time needed to train on that equipment was too time-consuming. One participant reported, “… we needed to have microscopy lab training to even start our research. We did not get that until the second week of lab week. My partner and I just lost lab time.”

Another “Program Concern” shared by some participants was accessibility issues experienced during the field trips. For example, one participant with mobility limitations was not able to climb to the top of the buffalo jump during the cultural site field trip, and not able to navigate the climb up a tower during the industry field trip to the hydroelectric dam. This resulted in a feeling of unintended isolation for that participant, who saw the value in the field trip, but also shared, “I’m not complaining, but I felt so isolated in that experience.”

A final “Program Concern” shared was the social divide that emerged for those living off-campus. As discussed, those participants that lived near the university chose not to live on-campus with the bulk of the cohort. Although they recognized this was their choice, they also indicated that the unintended consequence of their choices during the research experience was a sense of “missing out” on the group dynamic and informal team-building experiences. One participant stated, “So much happened beyond the 9-5 hours. I missed out.”

Recommendations for Future Cohorts. The final theme that emerged from analysis of the focus group data was “Recommendations for Future Cohorts.” Within this theme, two primary sets of recommendations were highlighted by participants. The first set of recommendations were around guidance for the laboratory mentors. Participants felt that mentors should provide them with more clear expectations or some sort of “general framework” at the start of their relationship. Also included in the suggested guidance for mentors was that there be some sort of weekly time requirement for collaboration between mentors and participants. Although many participants were quite content with the amount of time made available to engage directly with their mentors, others felt that more time was needed interacting directly with the research mentor instead of the other researchers working in those labs. The participants were quick to point out that they felt supported by the other researchers in the lab who were often undergraduate students, but still felt that “they just kind of passed you off to the grad student.”

The second set of recommendations that emerged within the “Recommendations for Future Cohorts” theme was focused on cultural connections. Participants suggested more travel around the state to different cultural sites, especially those cultural sites closer to their own communities. Participants felt that those additional trips might better support the rural teachers in the cohort. Another teacher, who is not Indigenous, suggested that she felt challenged incorporating Indigenous science knowledge into her teaching because she herself was not Indigenous. As a result, it was recommended that trips to reservations in the state or more clear partnerships with tribal colleges might support all participants, but especially those who were not American Indian.

DISCUSSION AND CONCLUSIONS

In response to the first research question that focused on the teachers’ self-efficacy, results indicated significant gains from before the program to the end of the program in participants' teaching efficacy beliefs. More specifically, from the beginning to the end of the summer program, teachers showed large significant gains in personal teaching efficacy beliefs in science and engineering, and a possible significant gain for mathematics. For the STOEB1, which measured participants' "teaching outcome expectancy beliefs," for above-average student interest or performance, the only significant gain from pre-survey to post-survey was in science, but with a large effect size. Therefore, apart from the science content area, teachers from the beginning to the end of the summer program showed little differences in their outcome expectancy beliefs for students who showed above-average interest or performance. For the STOEB2, which measures "teaching outcome expectancy beliefs" for neutral/below-average student interest or performance, there were no significant gains from pre-survey to post-survey. Teachers showed little differences in their outcome expectancy beliefs for students who were neutral or showed below-average interest or performance.

Further, results from the T-STEM survey suggest that there was significant growth in participants' confidence in teaching. Survey data indicates there was a substantial increase in how comfortable teachers felt about teaching engineering lessons post-program compared to pre-program. When combined with the results indicating the increase in personal teaching efficacy beliefs in science and engineering, findings suggest that the RET had an overall positive influence on the teachers' personal teaching efficacy beliefs in science and engineering and their confidence teaching engineering. The laboratory and field trip activities provided multiple opportunities for mastery experiences, which are suggested to be the most important contributing factor to self-efficacy (Lawrent, 2022). More specifically, mastery experiences were intentionally included to grow participants' content knowledge (CK) through the lab time, as increases in CK can serve as mastery experiences for science teachers (Palmer, 2006), and build their PCK through the professional development modules. Another contributing factor could be the focus of the RET on professional learning and support for teaching, and not on materials-focused innovations or training teachers to use a particular engineering curriculum (Cheung et al., 2017). Regardless, these results are compelling given previous research indicates that elementary teachers not only do not have any professional development in engineering education that resembles this RET (Banilower et al., 2018), but they also often lack confidence in teaching of engineering (Hammack and Ivey, 2017). Therefore, providing rich research experiences like those described here with deep and substantive exploration of engineering teaching could serve as a primary mechanism in enculturing self-efficacy in engineering education for elementary teachers. These findings are in alignment with the previous research suggesting that participating in engineering-education professional development can have positive impact on teachers' engineering teaching efficacy in pre-service teachers (Fogg-Rogers et al., 2017; Perkins Coppola, 2019; Smetana et al., 2019) as well as in-service teachers (Crawford et al., 2021; Utley et al., 2019). Further, experiences like those outlined in this program could afford them the professional development needed to not only teach engineering with confidence, but to build interest in engineering for their students and encourage them to begin identifying with engineering.

Our second research question focused on the attributes of the summer research program that contributed to the teachers' teaching practice. First, the professional development did not focus on training teachers to use specific materials or curriculum, but instead focused on developing participants' PCK in engineering (Reimers et al., 2015). This was accomplished by de-emphasizing specific engineering content and curricular materials (Cheung et al., 2017) in lieu of supporting the development of teachers' PCK through professional development on NGSS, IEFA, ISK, and UDL to develop engineering instruction using the 5E model.

Secondly, findings from the focus group data aligns with Mesutoglu and Baran (2021) research-based guidelines for the design of effective engineering professional development. The summer research program utilized a wide variety of instructional methods to support the teachers' professional development, including workshops, hands-on activities, and field trips to industry and cultural sites. The summer research program also provided extensive opportunities for the participants to work collaboratively with one another, the research mentors, and industry partners like those from the local power company. One professional development recommendation from Mesutoglu and Baran (2021) that did not fully emerge in our findings was the need to provide ongoing constructive feedback to participants. Although some of the teachers received informal formative feedback, and the cohort routinely participated in weekly talking circles (Rost, 2023) to share reflections with one another and the research team, there was no formal process for providing ongoing constructive feedback to the teachers about their professional growth. As we plan for future cohorts, these findings suggest that formative feedback through informal conversations and talking circles could be an effective method to investigate further. This could even be preferred for participants from underrepresented groups whose cultures might make them more inclined to learning orally through storytelling and conversation.

To align with the Indigenous participants' intertribal ontologies, the time, space, and method for privileging orality should be grounded in relationships in an effort to avoid the potential for problematic ethnoracial and cultural essentialism. These relationships are built over time. If done well, this could provide an avenue for participants to practice implementing the essential understandings within IEFA as part of the RET.

Related to cohort community building and relationships, another interesting finding from the qualitative data was the importance the participants placed on conversation. Most notably, participants remarked that the informal, "hallway" talk that occurred during mealtime or in the evening was one of the most influential factors in their professional growth and getting the most out of the research experience. Further, participants recognized that the on-campus living situation afforded those informal conversations and dialog with one another. Those participants that did live on campus shared how important those conversations were to their growth, while those participants that lived off-campus shared how much they felt they missed. Although living on campus will not be possible for all, that characteristic of the program was a seemingly central dimension of the entire experience, and consequently, will be encouraged in future cohorts. This was an unintended positive consequence of the on-campus housing and one that our research team did not initially anticipate. Finding creative ways to include off-campus participants in "hallway talk" is another area the project team is focused on for future cohorts. Additionally, exploring the components of "hallway talk" in more depth will be important to determine any connection with self-efficacy. One possibility is that hallway conversations represent a form of social persuasion or provide opportunities for vicarious leaning with peers, both of which are factors that have been identified to impact self-efficacy (Bandura, 1977).

It is important to emphasize that assessment of the final learning sequences, and the degree to which they were implemented in the school year with fidelity, was outside the scope of this study. Instead, the culminating artifact for the RET was the teachers' 5E learning sequence that they could then implement in the coming school year. While they each completed and submitted lesson plans, there was no requirement for implementation, and as such, no evidence or data related to implementation. Hence, the research team has not assessed the quality of the teachers' lessons because it was both outside the scope of the project.

With that said, the research team has already considered how this challenge might be addressed in Year 2. First, we have set up an independent study course to take place in the fall following the Year 2 cohort's research experience. This independent study will serve as a hub for sharing lesson refinement and implementation. In addition, we are exploring how we might fine-tune, or redevelop, tools for assessing the "high quality" nature of the resulting learning sequences. While reliable and valid instruments currently exist for assessing the quality of lessons as it relates to NGSS, IEFA, cultural responsiveness, or UDL, no single instrument exists that connects all the dimensions addressed in the RET participants' lessons.

In conclusion, findings from this study corroborate much of what is found in literature on teacher self-efficacy in engineering education. The lessons learned about the influence of the RET on teachers' self-efficacy, coupled with the lessons learned about what components most contributed to their professional development, should help guide future professional development efforts in other contexts that foster inclusive student engineering identity formation within their classrooms. Further, hundreds of rural and reservation elementary students will be directly impacted by the development, integration and assessment of culturally responsive engineering education instructional plans created via this interdisciplinary program.

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ABBREVIATIONS

CK: Content Knowledge; IAB: Industry Advisory Board; IEFA: Indian Education for All; ISK: Indigenous Science Knowledge; NGSS: Next Generation Science Standards; NSF: National Science Foundation; PCK: Pedagogical Content Knowledge; PSTEB: Personal Science Teaching Efficacy Beliefs; RCR: Responsible Conduct of Research; RET: Research Experience for Teachers; RM-ANOVA: Repeated Measures Analysis of Variance; SEP: Science and Engineering Practices; SSI: STEM Summer Institute; STEM: Science, Technology, Engineering, and Mathematics; STOEB: Science Teaching Outcome Expectancy Beliefs; UDL: Universal Design for Learning

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