2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #52690

The Impacts of Ongoing Professional Learning on Rural Elementary Teachers' Engineering Teaching Self-Efficacy (Fundamental)

Dr. Jenna Gist, Purdue University – West Lafayette

Dr. Jenna Gist is currently a Postdoctoral Scholar at Purdue University, and Adjunct Professor at American University. Her research interests center on the learning and development of preservice and inservice elementary teachers, with a focus on supporting high-quality science and engineering instruction. Dr. Gist also currently serves as the Assistant to the Executive Director for the Association for Science Teacher Education (ASTE).

Dr. Rebekah J Hammack, Purdue University – West Lafayette (College of Engineering)

Rebekah Hammack is an Assistant Professor of K-8 Science Education at Purdue University. She served as an Albert Einstein Distinguished Educator Fellow in the Division of Research on Learning in Formal and Informal Learning. Dr. Hammack's research focuses on the connection of local knowledge and context to STEM interest and identity development in youth, particularly rural and Indigenous youth in elementary and middle grades, as well as how elementary teachers develop teaching efficacy and identity as STEM educators. Through her research, Dr. Hammack aims to advance understanding of how to enhance STEM education in rural schools and communities, providing opportunities to meet the unique needs of underserved rural students.

Julie Robinson, University of North Dakota

Dr. Julie Robinson is an Assistant Professor at the University of North Dakota and the Director of UND's Center for Engineering Education Research. Her research explores strategies for broadening access and participation in STEM, focusing on culturally relevant pedagogy in science and engineering. She also investigates strategies for increasing representation in STEM through teacher professional learning opportunities and by exploring the impact of group gender composition on girls' motivation and engagement. Dr. Robinson is a PI and Co-PI on several NSF sponsored grant projects which focus on teacher professional learning and self-efficacy with implementing culturally relevant engineering education, connecting to place and community, and centering culture and Indigeneity within STEM education. Dr. Robinson has over twenty years of K – 12 teaching experience, including seven years as a teacher leader of professional development in the Next Generation Science Standards, the Common Core State Standards in Mathematics, and in elementary science and engineering pedagogy.

Min Jung Lee, University of North Dakota
Rudan Wang
Alisa Hee-Eun Chung, Purdue University at West Lafayette (COE)

The Impacts of Ongoing Professional Learning on Rural Elementary Teachers' Engineering Teaching Self-Efficacy (Fundamental)

1. Introduction

Engineering teaching self-efficacy is defined as teachers' beliefs in their capacity to produce desired engineering teaching outcomes [1] and is a critical factor in teachers' ability to enact effective engineering instruction [2]. Teachers with stronger engineering teaching self-efficacy are more likely to engage students in authentic engineering practices, persist through instructional challenges, and make pedagogical decisions that support student learning. However, prior research indicates that many elementary teachers report low confidence in teaching engineering, which can constrain both student learning opportunities and teachers' instructional decision-making [2], [3].

Professional learning (PL) initiatives have shown promise in supporting elementary teachers' engineering teaching self-efficacy by strengthening teachers' engineering content knowledge, pedagogical approaches, and familiarity with engineering practices [4], [5]. Despite these findings, much of the existing research relies on single-point assessments and limited data sources (e.g., surveys or interviews at a single timepoint), providing only a partial view of how teachers' engineering teaching self-efficacy develops over time. As a result, less is known about the ways in which sustained engagement in PL influences teachers' confidence and instructional practices as they work to integrate engineering into elementary classrooms.

These issues are particularly pronounced in rural contexts, where engineering instruction remains limited or absent in elementary settings [6], [7], [8]. Rural elementary teachers often face reduced opportunities to teach engineering and have limited access to engineering-focused PL, which can result in gaps in pedagogical knowledge and diminished confidence to teach engineering [2], [9]. Consequently, many rural elementary teachers report difficulty integrating engineering into their instructional practice [10]. Addressing these challenges is essential for expanding access to high-quality engineering education and promoting rural students' participation in engineering learning experiences.

This study addresses these gaps by examining how rural elementary teachers' participation in ongoing PL influenced their engineering teaching self-efficacy over time and by identifying the factors and experiences within the PL that most strongly supported teachers' efficacy development. The study was guided by the following research questions: (1) What, if any impact, does engaging in ongoing PL have on rural elementary teachers' engineering teaching self-efficacy? (2) What factors/experiences influenced teachers' engineering teaching self-efficacy during ongoing PL?

2. Background

2.1. Elementary Teachers' Engineering Teaching Self-Efficacy

As engineering education is gradually becoming a crucial component in K-12 education, teachers' engineering teaching self-efficacy has attracted more attention and has been recognized as a key factor influencing instructional quality, willingness to use reform-based practices, and persistence in long-term classroom teaching. Although there are mixed results on whether higher teaching self-efficacy could transfer to high-quality instruction [11], some research has shown that self-efficacy increases could translate into classroom practice in terms of increased instructional time or higher-quality instructional practices [12], [13], [14]. Conversely, lower engineering teaching self-efficacy could hinder the successful implementation of engineering standards in teachers' classrooms [15]. In elementary education, engineering teaching self-efficacy has been a fragile yet consequential belief system due to limited formal preparation [11].

Although teachers show interest in engineering teaching, a growing body of research indicates that elementary teachers exhibit low engineering self-efficacy and low teacher efficacy related to engineering pedagogical content knowledge, especially compared to their science and math teaching self-efficacy. For example, researchers employed the design, engineering, and technology (DET) survey of 192 elementary teachers from 18 states in the USA, and the results showed that elementary teachers are quite unfamiliar with DET, even though they thought teaching DET was important and showed interest in teaching engineering [3]. Furthermore, a study of 542 Oklahoma K-5 public school elementary teachers demonstrated that teachers' engineering self-efficacy and their related engineering pedagogical content knowledge are low, with significant differences across school context [15]. These findings align with national survey data showing that only a small proportion of elementary teachers feel well prepared to teach engineering, underscoring the significant lack of engineering teaching preparation pathways.

Prior research also suggests that low engineering teaching self-efficacy is affected by multiple factors. For example, researchers found that elementary teachers' low familiarity with engineering and design practice, rather than years of teaching experience, along with constraints related to time, training, and content knowledge, impeded the integration of engineering, while in-service PD in DET has remained limited [3]. It is necessary to help researchers and curriculum developers organize programs to address challenges in engineering teaching self-efficacy and pedagogical guidance through in-service programs, such as teaching and professional development [11], [16].

Methodologically, Yoon and colleagues [2] employed data from 434 teachers in 19 states to develop and validate the Teaching Engineering Self-Efficacy Scale (TESS), which consisted of 23 items from four categories (engineering pedagogical content knowledge, engineering engagement, engineering disciplinary self-efficacy, and outcome expectancy), marking a significant advancement in the field. Collectively, these studies indicate that while engineering education is increasingly emphasized at the policy level, without targeted supports, elementary teachers' engineering-teaching self-efficacy remains insufficient to meet the expectations of the education reform reflected in the Next Generation Science Standards (NGSS).

2.2. Impacts of Professional Learning on Elementary Teachers' Engineering Teaching Self-Efficacy

PL has been a necessary component for increasing elementary teachers' engineering teaching self-efficacy. Research has shown that long- or short-term, well-designed PL can produce meaningful gains in teachers 'confidence; beliefs; willingness to engage in instructional practice;

and classroom enactment in engineering; although the magnitude and longevity of these gains vary based on PL design features. Short-term, curriculum-embedded PL- particularly those centered on Engineering is Elementary (EiE)- has been demonstrated to be an effective tool designed to enhance elementary teachers' engineering teaching self-efficacy [11]. For example, one study reported that the majority of participants reported increased self-reported confidence in facilitating engineering activities after taking the one-day EiE PL workshops, especially among elementary teachers who had never used EiE before and were likely unfamiliar with engineering and technology in the classroom [17]. Similarity, qualitative findings from a two-week EiE-focused PL enhanced teachers' understanding of engineering practices and pedagogical strategies, while the persistent resource-time, funding, materials, and knowledge constraints hindered full implementation.

Compared to short-term workshops, sustained PL appears to yield more robust and transferable gains in engineering teacher self-efficacy. Crawford et al. [18] examined a semester-long, 3-hour weekly classroom meeting that involved 15-week NanoEnvironmental Engineering for Teachers (NETT) graduate-level courses for 41 K-12 in-service teachers, demonstrating significant gains in teachers' self-efficacy, building their confidence in technical skills, and providing beneficial PD. Gardner et al. [19] offered an additional year-long EiE PL workshop in an integrated STEM context for middle school and secondary teachers from non-STEM focus schools and reported improvements in self-efficacy and proactive changes in classroom teaching; however, researchers found no change in content knowledge. This study highlights the importance of mastery experience, pedagogical knowledge, and reflective practice (e.g., instead of the content knowledge alone) in shaping teachers' self-efficacy. Furthermore, several factors have been identified as critical in PL programs. Sargianis et al. [17] emphasized the salience of including both student and teacher perspectives, foundational knowledge, and active learning as primary mechanisms to support effective PL. Additionally, Crawford et al. [18] emphasized the importance of immersing teachers in place-based learning to more effectively engage students in content enrichment, engineering design, and reflective practices within real-world contexts. These factors align with the broader PL literature that suggests duration, coherence, opportunities for classroom enactment, and active learning are key features of effective PL programs.

Further, the literature positions PL as fundamental in supporting elementary teachers' engineering teaching self-efficacy, particularly when PL is sustained, practice-based, and aligned with the curriculum [18]. Consequently, there is an emergent need to examine the effects of engineering-focused PL in other school contexts (e.g., rural), and understand how elementary teachers develop engineering teaching self-efficacy over time and across contexts.

2.3. Engineering Instruction in Rural Communities

While rural places can provide numerous opportunities for meaningful engineering learning, engineering instruction in rural communities comes with its own particular set of challenges. Rural educators face hardships related to geographic isolation and higher workloads [20], [21], [22]. Rural teachers often express a lack of necessary class materials, resources, and professional development [20], [23], as well as an increased demand from having to teach across multiple subjects or grade levels. Working in rural locations may also lead to more limited access to certain amenities that are present in urban areas, as well as a comparatively lower salary and fewer advancement opportunities [21]. Furthermore, there exists a lack of preservice training and in-service specialized professional development to prepare teachers for the unique challenges of rural instruction [20], [21], [22]. Ultimately, these factors all contribute to the difficulty in recruiting and retaining quality teachers in rural schools [21], [22].

Elementary teachers face additional challenges. For example, several elementary teachers have discussed feeling uncomfortable teaching engineering or being intimidated by engineering due to their perceived lack of content and pedagogical content knowledge, which has contributed to low engineering teacher self-efficacy [20], [23]. As a result, engineering instruction has often been excluded from elementary classrooms or taught in very limited amounts. Further, some of the teachers who are enthusiastic about teaching engineering face structural challenges or pressures that discourage them from doing so [23]. Emphasis on subjects pertaining to high-stakes testing, such as literacy and math, combined with a lack of time in the school day to teach or prepare engineering, places additional pressures on elementary teachers to forgo including engineering instruction in their classrooms [23]. In other cases, teachers who wish to incorporate engineering into their classrooms may feel unsupported or micromanaged by administrators, adding additional strain [23]. Structural challenges such as limited access to engineering-focused professional learning opportunities are especially pronounced for rural elementary teachers [21].

Together, these challenges highlight several needs of rural elementary teachers. The lack of PL opportunities and curricular resources and related low engineering teacher self-efficacy demonstrates a need for PL to assist rural educators in receiving quality engineering education training and necessary teaching materials [20], [23]. Additionally, there is a need to provide pre-service teachers with more rural field experiences and specialized PL to improve their understanding of the challenges of rural teaching [20], [21], [23]. The large struggle to recruit and retain teachers who are willing to work in rural areas highlights a need to change the current dominant narrative and deficit views about rural teaching with ones that highlight the unique benefits and opportunities of rural teaching [22].

Although rural instruction comes with numerous challenges, it also offers many advantages. Arguably, the greatest asset rural teachers have is the opportunity to form deep connections with their students and wider community [22]. As such, they also have a greater chance of fulfilling roles beyond classroom teaching (e.g., mentors) [22]. Rural educators also have greater autonomy and, in some cases, smaller class sizes, which allow them to address problems creatively or test out different teaching strategies that deviate from more traditional methods [21], [22]. Rural education also offers more opportunities for informal learning and for teachers to experience a slower-paced and more community-oriented lifestyle [21]. Changing the deficit view of rural teaching and providing teachers with the training, materials, and support they need may help combat the large STEM teacher shortages in rural areas and enable marginalized students in rural areas to gain access to quality engineering education.

3. Conceptual/Theoretical Framework

To frame the current study, we focused on engineering teaching self-efficacy, and utilized Bandura's theory of self-efficacy [1] to investigate the ways in which rural elementary teachers developed confidence in teaching engineering after engaging in ongoing PL.

3.1. Bandura's Theory of Self-Efficacy

Bandura's theory of self-efficacy [1] provided a useful and well-established framework for examining how rural elementary teachers develop confidence in teaching engineering through participation in PL. Within this framework, self-efficacy refers to individuals' beliefs about their capability to organize and execute actions required to achieve desired outcomes [1]. In the context of elementary engineering instruction, engineering teaching self-efficacy reflects teachers' beliefs in their ability to design, implement, and facilitate meaningful engineering learning experiences for their students.

According to Bandura, self-efficacy is developed through four primary sources: mastery experiences, vicarious experiences, social persuasion, and physiological or emotional states [1]. *Mastery experiences*—such as successful teaching or learning experiences—are considered to be one influential source of efficacy [1]. For elementary teachers, opportunities to actively engage in engineering design tasks and successfully implement engineering lessons can strengthen beliefs in their instructional capabilities. *Vicarious experiences* occur when teachers observe peers modeling effective engineering instruction, allowing them to compare their own abilities with those of others and envision themselves enacting similar practices [1]. *Social persuasion* includes feedback, encouragement, and support from PL facilitators and peers [1], which can reinforce teachers' confidence and motivation to persist in teaching engineering. Finally, *physiological or emotional states*, such as anxiety, excitement, or enjoyment, influence how teachers interpret their ability to teach engineering and respond to instructional challenges [1].

Within PL contexts, intentional design features such as hands-on engineering design experiences, collaborative work with peers, and structured opportunities for reflection can support the development of engineering teaching self-efficacy across all four sources [1], [2], [3]. Through repeated engagement in these PL experiences, teachers may build confidence not only in their engineering content knowledge but also in their ability to facilitate engineering practices in elementary classrooms. Consequently, PL that leverages multiple sources of self-efficacy may promote sustained engagement in engineering teaching and support teachers in integrating engineering more effectively into their instructional practice.

4. Methods

The four primary sources of self-efficacy (e.g., mastery experiences, vicarious experiences, social persuasion, and physiological or emotional states) present within Bandura's theory of self-efficacy [1] informed our PL development and approaches to data analysis as described below.

4.1. Study Context

This study is a part of a nationally funded research project that examines how rural elementary teachers' ongoing participation within a larger PL community (PLC), and embedded engineering learning community (ELC), impacts their science and engineering practice. What follows is a description of the PL that teachers engaged in during both years (years one and two) of the PL program.

4.1a. Year One Professional Learning Activities

During the first year of the PL program, ~180 rural elementary teachers across four states participated in a weeklong virtual intensive summer institute, followed by seven synchronous online meetings (~ 90 minutes/meeting) during the following academic year. The focus of the summer institute was to introduce and engage teachers in understanding the NGSS, community relevant engineering design (CRED) framework [24], scientific phenomena, Science and Engineering Practices (SEPs), and the effective use of STEM notebooks in elementary classrooms. During the subsequent academic year (year one), teachers engaged in multiple PLC sessions that emphasized high quality science and engineering instruction and three-dimensional assessment. Beyond attending the PLC sessions, teachers implemented science and engineering lessons into their classrooms and completed the T-STEM survey [25] at different timepoints within year one of the program (e.g., pre-PL; immediate post-PL; and end-of-year).

Additionally, a subset of rural elementary teachers (~20 teachers) were selected to participate in a smaller ELC, where they engaged in additional, targeted PL around NGSS-aligned engineering instruction and the CRED framework. Beyond attending ELC sessions, teachers' video-recorded themselves teaching NGSS and CRED-aligned engineering lessons in their classrooms and engaged in additional reflection around their engineering lesson implementation through attending ELC meetings.

4.1b. Year Two Professional Learning Activities

Similar to year one of the PL program, participants in year two of the program engaged in a two-day intensive summer institute that focused on reorienting teachers to NGSS-aligned science and engineering instruction and the CRED framework. During the following academic year (year two), participants engaged in multiple, interactive PLC sessions and were provided additional opportunities to implement NGSS-aligned science and engineering lessons into their classrooms. Participants again completed the T-STEM survey at various timepoints throughout this year of the PL program (e.g., pre-PL; immediate post-PL; and end-of-year).

In parallel to year one, a subset of teachers continued to participate in additional ELC sessions that were focused on high quality engineering instruction. Teachers were provided with further opportunities to record themselves teaching CRED-aligned engineering lessons and engaged in deeper reflection on their engineering practice/lesson implementation through completing a video showcase and reflection protocol in small groups. All ELC teachers also completed an additional end of program interview and created end-of-year engineering teaching confidence graphs. Figure 1 summarizes all PLC and ELC PL activities. Table 1 showcases how all PL activities were aligned with Bandura's four primary sources of self-efficacy.

Figure 1. Timeline of Research and PL Program Activities

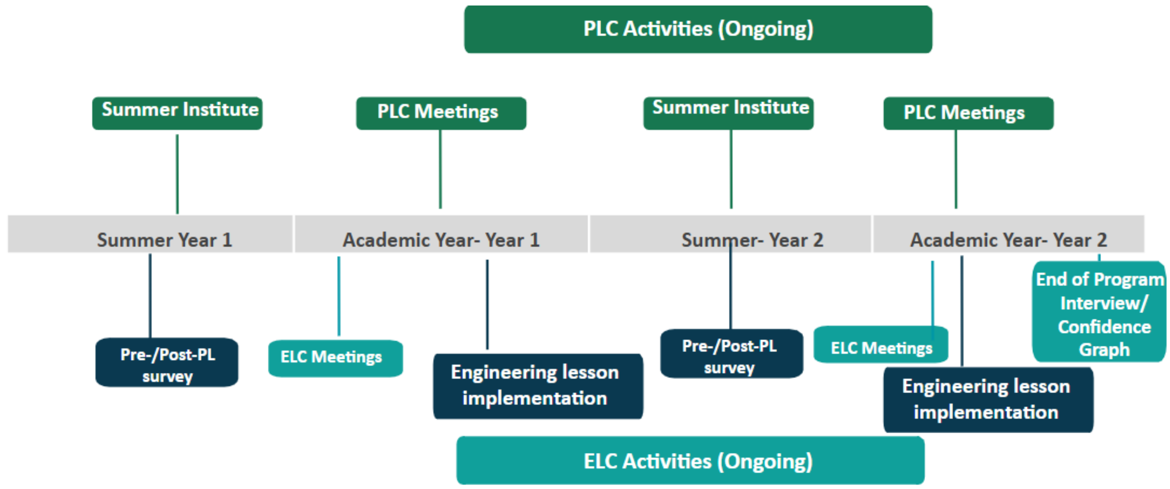


Table 1. Alignment of PL Program Activities to Bandura's Sources of Self-Efficacy

Bandura's Sources of Self-Efficacy	**PLC/ELC Activities**
Mastery experiences	• Engineering lesson planning/implementation (PLC and ELC)
Vicarious experiences	• Summer institutes (PLC) • PLC and ELC meetings • ELC video showcase/reflection protocol
Social persuasion	• Summer institutes (PLC) • PLC and ELC meetings • ELC video showcase/reflection protocol
Physiological or emotional states	• Summer institutes (PLC) • PLC and ELC meetings • ELC video showcase/reflection protocol

4.2. Participants

For this study, nine teachers' engineering teaching self-efficacy was examined over two years in response to the ongoing PL. All nine teachers were selected based on the following selection criteria: (a) participation in both PLC and ELC activities within the PL program; (b) completion of all data collection measures (see section 4.3); and (c) variation in their engineering teaching self-efficacy development across the PL program. Table 2 provides an overview of each teacher participant, including their pseudonym; grade level/grade band; and years of rural elementary teaching experience.

Table 2. Participants' Background Information and Rural Teaching Experience

Pseudonym	**Grade Level/ Grade Band**	**Years of Rural Elementary Teaching Experience**
Andrew	3rd-5th	6-9
Hannah	K-6th	20+
Macey	K-6th	20+
Sebi	4th	6-9
Greta	3rd	6-9
Olivia	5th	3-5
Brielle	3rd	3-5
Hunter	5th	10-20
Laura	4th	10-20

4.3. Study Design and Data Sources

We utilized a multiple case study approach [26] to examine rural elementary teachers' engineering teaching self-efficacy over two years in response to the ongoing PL. Within this study, we defined a case as an individual teacher and their rural teaching context during the two-year PL program. For each case, we collected and analyzed the following data sources at different points during the PL program: (a) the Teacher Efficacy and Attitudes towards STEM (T-STEM) survey [25] (i.e., collected pre-PL, immediate post-PL, and end-of-year during years one and two of the PL program); (b) end-of-program interviews (i.e., collected end of year two); and (c) teacher-generated engineering teaching confidence graphs (i.e., collected end of year two).

4.4. Data Analysis

Data were examined through use of within-case analysis [26], informed by Bandura's sources of self-efficacy [1]. We utilized within-case analysis to provide an in-depth exploration of each teacher's engineering teaching self-efficacy development, while also preserving contextual richness that may have been lost in decontextualizing data across multiple cases for broader comparison [26]. Our analysis process involved multiple steps. First, all data sources were deidentified and organized. Next, for each case, researchers examined teachers' T-STEM survey responses, engineering teaching confidence graphs, and end of program interviews. Guided by Bandura's four primary sources of self-efficacy (e.g., vicarious experiences; mastery experiences; social persuasion; and physiological or emotional states), we coded all data sources: first, through conducting open coding [27]; and second, through utilizing deductive coding [27]. This process entailed coding all data sources in light of Bandura's four primary sources of self-efficacy and writing analytic memos to describe which factors/experiences within the ongoing PL program were most salient to each teacher's engineering teaching self-efficacy development. These memos were then used to inform how each case was presented within the findings.

5. Findings

Findings underscored the multifaceted and individualized nature of how teachers developed self-efficacy over time in response to the PL, emphasizing the significance of vicarious and mastery experiences within the PL to promote teachers' engineering teaching self-efficacy. What follows is a presentation of cases to showcase how different teachers' engineering teaching self-efficacy developed throughout the PL by triangulating their interviews, engineering teaching confidence graphs, and T-STEM survey responses.

5.1. Case 1: Andrew

Andrew's self-efficacy survey scores started out relatively strong (4.18) and rose immediately after the summer PL (4.27) but after teaching his first engineering lesson, they had dropped to below the pre-survey level (4.00). Despite this drop, his scores rose substantially (4.00 to 4.64 points) by the beginning of year two PL and continued to increase through the end of year two (4.73).

In his interview, Andrew shared that he felt pretty confident about his engineering teaching abilities going into the first summer PL because he had engaged in previous STEM PL (content mastery experience) as part of his Gifted and Talented endorsement training. When he actually taught the engineering lesson he developed for our PL though, his confidence dipped because he was not able to teach the lesson well in a short period of time:

> "It kind of dipped down. I realized I felt like I needed to do it quickly, be able to do these in one or two sessions, and I realized I really wasn't able to do it in one or two sessions…and it just didn't work out or didn't work out how I wanted it to, I guess. And so that kind caused it to dip" (interview).

While his efficacy had dropped after teaching the lesson, it went back up sharply after engaging in PLC meetings with other teachers in the program.

> "I think the biggest thing from last year was being able to just meet with other people that were implementing these same kind of tasks…And just being able to talk and find out what those teachers were doing in their classroom compared to what I was trying to do. So that's kind of where I came up, not came up with the idea, but resolve that this year when I was doing it, I was going to take more time and give them some more criteria and constraints to get some more realistic solutions out of the students was during that part. And I think that was helpful because some of the other people had already went ahead

> and done that. So it was good to get their perspective on how they were doing that and what kind of benefits they felt they were getting from that" (interview).

During these ELC sessions, Andrew was learning vicariously through his peers, resulting in an increase in his self-efficacy. He shared that "being able to hear from people that have done these things that have come up with these creative ideas, that is definitely something that I enjoy seeing" (interview). He took the ideas his peers shared and adjusted his own engineering teaching and felt very successful after teaching his second lesson (mastery experience) and displayed another increase in self-efficacy.

5.2. Case 2: Hannah

As a veteran teacher, Hannah shared that she came into the program with very high self-efficacy for teaching engineering,

> "I have been doing engineering for so long that yeah, I was already comfortable…so it's not really a very fair judgement of how good [the ELC] was because I was already really comfortable with it" (interview).

However, her survey scores did not reflect the high level of self-efficacy she shared in the interview. Her efficacy levels for teaching engineering started at 3.36 prior to attending the first summer PL and rose to 3.91 immediately after the PL. Her scores remained at 3.91 until the second end of year survey, at which point they slightly dipped to 3.73.

Throughout the interview she discussed shifts in how she thought about teaching engineering and some of the factors that impacted those shifts. Hannah shared that watching the video tape of her lesson further built her confidence because she was able to notice all of the good things she did throughout her teaching.

> "I could see that, yeah, I was hitting this SEP and this SEP and this SEP, I'm like, okay, then it didn't fall apart as bad as I thought. Sometimes just that extra confidence in it. I think even though I'm a veteran teacher, it's kind of nice to hear that you are doing what you need to be doing. So I think the confidence part too is definitely helpful" (interview).

She went on to describe how her engineering self-efficacy has shifted over the project.

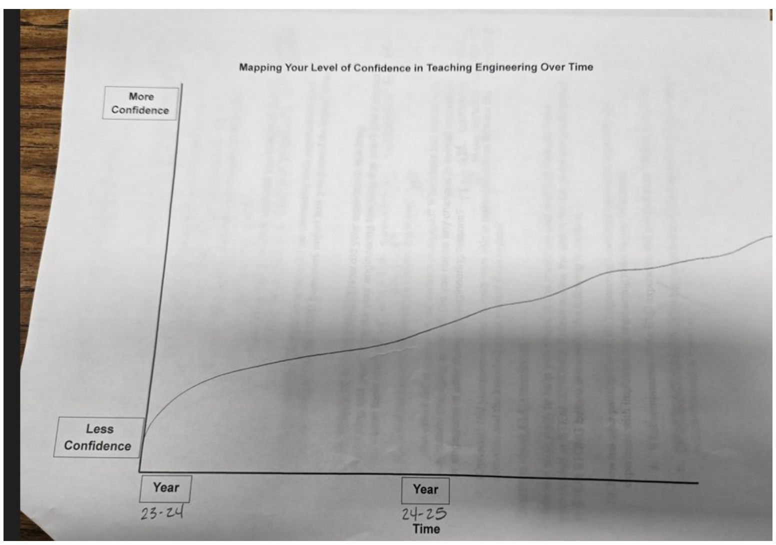
> "It's not so much that it's increased, but it shifted, I think, and again, it just comes back to that teaching engineering as a standalone as compared to really integrating it as part of our science and using science to support engineering to some extent, but more using the engineering to support science. And I think that's where my confidence has grown. Like, okay, we can fit this in here. And just thinking about other ideas of places that we can integrate it. And that's probably my biggest area of growth, not so much, oh, I'm a better engineering teacher, but just I'm a better teacher kind of. Yeah, because it is integrated" (interview).

For Hannah, changing her practice from teaching engineering as a standalone discipline to teaching in a way that integrates science and engineering together was "a shift in my teaching…that's important. That's a big effect" (interview). She also described the importance of connecting her local community to her engineering teaching by thinking about how local contexts "affect the students" and designing engineering design tasks that are "authentic" for her students. These particular comments highlight the importance of psychological and emotional states in shifting Hannah's self-efficacy.

5.3. Case 3: Macey

Upon entering the project, Macey did not feel confident teaching engineering, but her self-efficacy gradually increased throughout the two-year intervention. Macey's initial low confidence was evident in her confidence graph (see Figure 2), which began at the baseline level. While the modest gains in Macey's confidence were reflected in both the confidence graph and the survey, there was a discrepancy between the two datasets regarding her initial confidence. Survey responses indicated her initial confidence level at 2.45, which increased to 3.27 by the end of year one. This level of confidence remained through the beginning of year two before declining slightly to 3.09 as the year progressed. She also noted in her interview that she was halfway to having full confidence. This was reflected when she stated, "I probably went maybe halfway. I'm not really, really confident, but I was less confident last year, and I went about halfway" (interview).

Figure 2. Macey's confidence graph



According to the survey, she felt most confident in her potential for professional growth in teaching engineering (i.e., I am continually improving my engineering teaching practice). Also, her confidence grew mostly in her understanding of engineering concepts (e.g., I understand engineering concepts well enough to be effective in teaching engineering) and in her capacity to answer students' questions (e.g., When teaching engineering, I am confident enough to welcome student questions.).

During the interview, Macey shared that her mastery experience of teaching the engineering lesson in year one helped her to feel more comfortable teaching it in year two. Macey articulated this growth, stating:

> I did feel more comfortable. Having done it [engineering lesson] last year made me more comfortable to do it this year. I think I understood more this year how to do it than I did last year (interview).

She specifically elaborated that prior teaching experience helped her to explain the engineering concept “better to them [students] so they would understand better of what I wanted them to do”. Additionally, this mastery experience fostered comfort:

> Sometimes projects don't work and you have to revamp them and redo them and see in another way that they work because it's frustrating when things don't work. So I get frustrated. So that helped me say ‘okay guys, it's okay if things don't work. We can go back and change things and see if it works this time’ (interview).

Finally, though Macey did not feel fully confident teaching engineering, after teaching engineering lessons for the last two years, she expressed her commitment to teaching engineering in the future, as she noticed how engineering learning benefits students.

> “I need to start doing more things like this because it's more fun for them, homework for me, but it's more fun for them, so I need to start doing these more. That's what I realized” (interview).

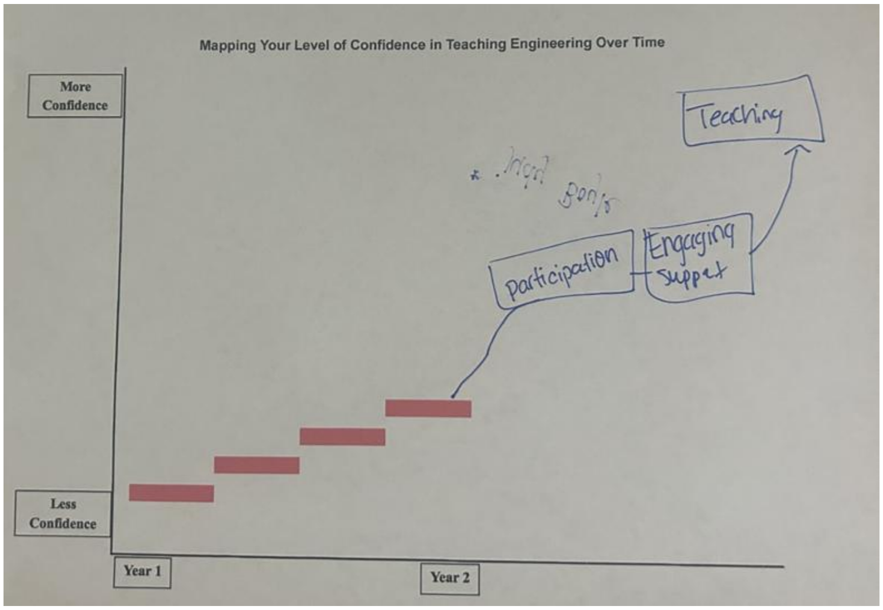
As a multi-grade teacher instructing the same students for multiple years, she observed the reciprocal development between her and the students:

> This year, I think they [students] got more detailed and thought more about it because this was their second year doing it. So I think that's how it got better (interview).

5.4. Case 4: Sebi

Sebi entered the project with notably low confidence, which increased substantially over time. Her initial confidence level started off at 1.18, rising to 3.73 by the end of year one, and reached 4.63 at the end of year two. This positive shift was also reflected in her confidence graph (see Figure 3). While year one showed consistent growth, Sebi attributed her heightened confidence in year two to the participation in the project and the support from the project members (social persuasion), noting that her teaching confidence in engineering reached its peak as she “kept teaching the engineering practices” (interview), which reflects the impact of mastery experience.

Figure 3. Sebi’s confidence graph



Several ELC activities contributed to Sebi’s confidence as Bandura’s primary sources of self-efficacy. Initially, small-group discussions with other teachers (vicarious experiences) helped her “narrow it [engineering lesson] down to what my kids were going to do,” while alleviating feelings of isolation as she realized the common feelings, situations, and challenges of teaching the lesson (physiological states).

> It just made me feel not alone because a lot of the other teachers felt the same way: ‘Oh, I don't think my lesson was good enough’. But, I've seen a lot of good things that all the different teachers shared in their video, so just we had a lot in common (interview).

Additionally, video-recorded lesson reflections in year one allowed Sebi to “see some of my [her] strengths and weaknesses” (interview) and improve her lesson (mastery experience). She also found the SEP poster activity, which involved comparing and connecting SEPs to classroom instruction, valuable for visualizing abstract concepts (content mastery experience). After participating in the project for two years, Sebi described her confidence in her pedagogical shift in teaching engineering.

> It has helped me step back and give the students more time to process the information and understand the why behind the science instead of just telling them why having them question and the inquiry part of it, asking questions, and having them figure it out instead of me just telling them the answer. I think that's a big part of it [my confidence growth] (interview).

With her new upper-grade students, Sebi felt less confident than before because she was unfamiliar with the standards for that grade. However, her confidence remained the same with reading and translating the science and engineering standards.

> I've been in eighth grade for a month, so I would say now it's kind of back to low confidence only because I'm not familiar with the eighth-grade standards, but I do feel more confident in diving into the standards, and I kind of know what to expect now and how to make connections with engineering practices (interview).

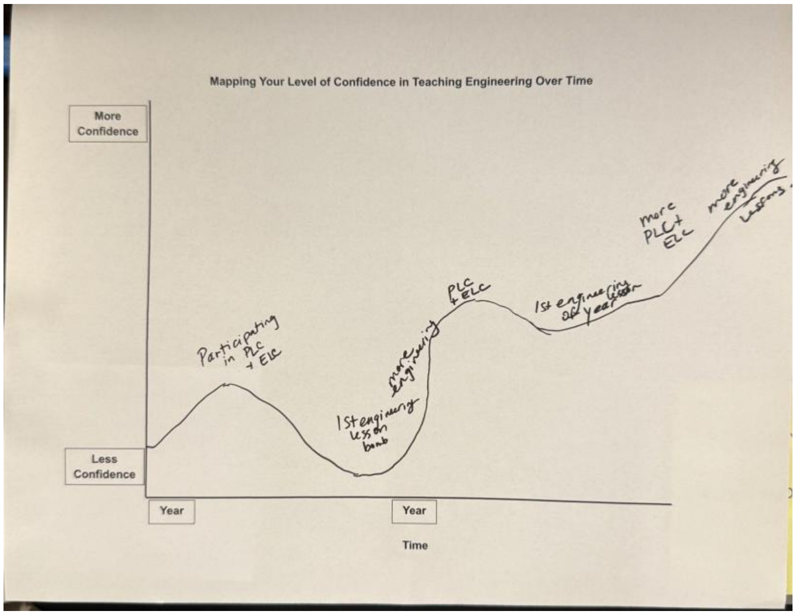
Finally, Sebi expressed a commitment to continuing engineering instruction as well as the need to maintain meaningful connections to the science content and the engineering practices.

> I think just continue to remember to incorporate those engineering practices and especially the building part…… They've [Students] already been asking if they could do an egg drop year, and I'm like, okay, well, let me think about what the science behind that is. So just knowing, still make it fun, but connected of course to the engineering practices (interview).

5.5. Case 5: Greta

Greta's self-efficacy trajectory showed an inconsistent pattern of growth over the two-year project timeline. Both her confidence graph (see Figure 4), on which she noted her starting point in the "less confidence" range, and her T-STEM score (3.36) at the beginning of the project indicated a low level of confidence to teach engineering prior to the PL. However, immediately following the PL activities, Greta's self-efficacy grew notably. Her T-STEM score rose to 4.09, and her confidence graph showed a moderate upward curve. As she explained, "I kind of felt like it was simple. Like, oh, this isn't so hard" (interview). Interestingly, when it came time to teach her first engineering task, Greta felt far less confident with actually implementing an engineering lesson than she had after experiencing the PL. "And then when I actually got to the point of doing the engineering part of the lesson, I was like, I have no clue what I'm doing because I've never done this before" (interview). Even after teaching the lesson, Greta's end-of-year data and confidence graph confirmed her decrease in self-efficacy, with her T-STEM score reverting back to its pre-PL score of 3.6, and her confidence graph showing a dip that was even lower than her original baseline starting point. She noted on her graph that the lesson was a "bomb", and the most significant score decreases were for questions such as, "I know the steps necessary to teach engineering effectively." and "I wonder if I have the necessary skills to teach engineering" (T-STEM).

Figure 4. Greta’s confidence graph



Greta described her self-efficacy increasing more in the second year of the project, however, with an additional dose of PL and more opportunities for practice and experience.

> I feel like it went up a lot, especially the second year. I don't know, something about you're a second year in this thing was like, I've done this, I know I can do this. And so I think it went up, it kind of dipped, and then we had more PLC in ELCs, and I feel like the collaboration was valuable, very valuable. And so then now I think, okay, well, I definitely can do this a lot more (interview).

Greta’s reflections on her confidence, showing the impact of social persuasion and vicarious experiences, were illustrated in her second year data as well. After the second round of PL at the beginning of the year, both her confidence graph and T-STEM scores showed increases. While her self-efficacy score did not quite reach its initial high from the first year (3.91 compared to 4.09), her confidence graph showed a steeper increase and higher peak than in the first year.

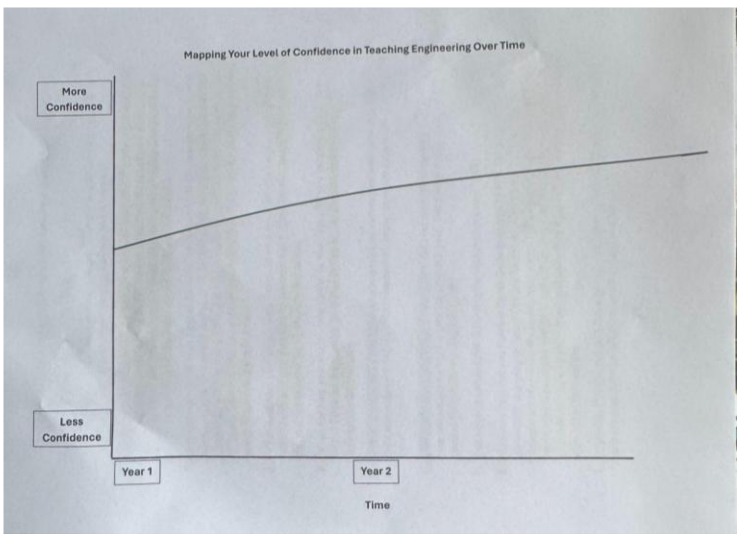
Similarly, but far less dramatically than in year one, Greta’s self-efficacy dipped slightly after teaching her engineering task. While her confidence graph showed a still higher peak than in her first year, her end-of-year T-STEM score decreased slightly down to 3.82.

Despite this variability, Greta’s overarching self-efficacy showed an upward trend over the course of the two years of project participation, and her interview responses confirmed that on-going practice, exposure, and collaboration with colleagues supported her increased confidence over time in teaching engineering. Further, Greta recognized that it was not just her confidence that was increasing, but explained that her teaching practice was improving as well. “And so learning different ways to incorporate all of those together. And again, the more you do it, the more you practice. So the more you practice, the better you get, as with everything” (interview). The opportunity for these mastery experiences, as she explained, “helped me to improve not only confidence I think, but my teaching” (interview). Greta also described other takeaways from her increased confidence in teaching engineering, such as providing more freedom and groupwork for her students, feeling comfortable telling students if she did not know the answer to something, and having more motivation to continue to grow and improve her practice. "I don't want it to stop. I want to keep going onward and upward and teaching my kiddos how to incorporate engineering into our lives" (interview).

5.6. Case 6: Olivia

Olivia began the project with significant prior engineering PL, and her self-efficacy trajectory across all data sources reflects minimal change over the two years. Olivia indicated a moderate starting level of confidence on her graph (see Figure 5), with her baseline beginning in the middle of the "less" and "more" confidence axis. Her T-STEM score prior to the year one PL was 4.27, with her lowest score for the item, "I wonder if I have the necessary skills to teach engineering." In reflecting on her growth in confidence, Olivia explained, "Yeah, it's not real steep, but I think that goes back to, we talked about that before…this is probably my fifth year of doing stuff like this. So I mean, definitely the confidence level goes up and anything I can learn from an experience is always good" (interview).

Figure 5. Olivia's confidence graph



While Olivia's confidence graph line was fairly flat, ending only slightly higher at the end of year two than at the beginning of year one, her T-STEM scores showed more variability. While a very small shift, her scores decreased from 4.27 to 4.09 to 4.00 over the course of the first year, reflecting beginning of the year, post-PL, and end-of-year changes. However, at the beginning of the second year, even prior to PL, her T-STEM score had increased to 4.91, with the same item as before ("I wonder if I have the necessary skills to teach engineering.") being her lowest score. While a less dramatic decrease in year one, by the end of year two, Olivia's overall T-STEM score was 4.36, which was higher than her initial starting point but still lower than at other times throughout the PL.

Despite these slight changes, Olivia discussed that her sense of self-efficacy continued to increase over the course of the project, particularly in specific ways. Having more resources and tools was a contributing factor, as were on-going mastery experiences in which she could practice and gain experience with teaching engineering. “I was more comfortable with the process. I've done, just having more experience under my belt” (interview). Olivia also discussed how specific skills, like her classroom management, familiarity with materials, and confidence with delivery had increased. “I think just competence level has grown. There's less pauses from me as a teacher gathering my thoughts because I'm more comfortable and I'm not pausing to come up with words like I'm doing right now” (interview). Overall, Olivia spoke about her engineering teaching with confidence and reflection on the specific aspects of her practice that on-going PL and experience had continued to influence. As she stated, “it's not my first rodeo with engineering” (interview).

5.7. Case 7: Brielle

Analysis of T-STEM survey and interview data indicated significant growth in Brielle’s engineering teaching self-efficacy following sustained engagement in the PL. Quantitative self-efficacy scores from the T-STEM survey demonstrated a clear upward trajectory over the two-year period. Prior to participation in PL, Brielle’s T-STEM score was 3.55. By the end of year one, this score increased to 4.00, indicating moderate gains in self-efficacy associated with initial implementation of engineering instruction. By the end of year two, her self-efficacy score increased further to 4.91, representing her highest reported level of self-efficacy across the study period. Brielle’s confidence graph mirrored these trends, reflecting overall positive growth in her engineering teaching self-efficacy despite minor fluctuations during interim data collection points.

While Brielle’s self-efficacy increased steadily across year one, interview data suggested a more nuanced pattern during year two. Although confidence continued to rise in the pre-PL survey at the beginning of year two, Brielle described a brief dip in efficacy immediately following PL sessions, which she attributed to increased awareness of the complexity and intentionality required for high-quality engineering instruction. However, by the end of year two, her self-efficacy rebounded and exceeded all prior levels, as she reflected, “Overall, I think I feel more comfortable to try new things and to guide kids through different engineering practices… just because I do have that experience that I didn’t have last year or didn’t feel comfortable trying last year” (interview).

Qualitative data illuminated several experiences that were particularly influential in supporting positive shifts in Brielle’s engineering teaching self-efficacy. One such experience was participation in an ELC video showcase and reflection protocol, where Brielle shared classroom footage of an engineering design lesson and received feedback from peers. She described this experience as affirming, noting that hearing others recognize students’ engagement in the SEPs contributed to a sense of professional validation: feedback that students “seem like they know what they’re doing” (interview) led her to conclude, “Oh, I actually do know what I’m doing. It is working” (interview). This form of social persuasion and vicarious experience appeared to strengthen her self-efficacy in both her instructional decisions and her understanding of the SEPs.

Students’ positive responses to engineering design lessons also played a critical role in shaping her self-efficacy. Observing students successfully engage in collaboration, redesign, and problem solving reinforced her belief that she could effectively guide learners through engineering practices. Reflecting on her growth in year two, she stated, “I feel more comfortable to try new things and to guide kids through different engineering practices… just because I do have that experience that I didn’t have last year or didn’t feel comfortable trying last year” (interview). These reflections suggest that mastery experiences accumulated over time were central to her developing efficacy.

Brielle also attributed her increased self-efficacy to concrete instructional supports introduced through PL, particularly the CRED engineering lesson framework. She described, “I’ve redone [the CRED] lesson model I don’t know how many times… it’s so easy to follow and there’s such a great opportunity for collaboration and hands-on and redesigning”, emphasizing its clarity, accessibility, and alignment with collaborative, hands-on learning. Having a reliable engineering lesson framework appeared to reduce uncertainty and support intentional implementation, contributing to sustained self-efficacy growth.

By the end of year two, Brielle’s engineering teaching self-efficacy had expanded beyond confidence in her own classroom practice to include confidence in supporting colleagues. Although she reported lingering uncertainty after year one—particularly related to inconsistent engineering lesson implementation and contextual challenges (e.g., new grade level and district) she described a marked shift by the conclusion of year two. She stated, “I definitely feel more confident. I feel like I could lead coworkers to navigate through different STEM activities or help them set it up and to offer guidance or direction” (interview). Engagement in ongoing PL not only increased her engineering self-efficacy but also reshaped her perceptions of herself as a STEM teacher. Together, these findings illustrated how sustained PL, coupled with reflective practice, peer validation, and successful classroom experiences, supported significant and lasting gains in her engineering teaching self-efficacy.

5.8. Case 8: Hunter

Survey and interview data indicated a non-linear pattern of change in Hunter’s self-efficacy for teaching engineering across the two years of PL. T-STEM self-efficacy scores decreased slightly from pre-PL in year one (3.91) to the end of year one (3.82), followed by a substantial increase by the end of year two (4.45), representing the highest reported engineering teaching self-efficacy level for this participant.

Interview data helped explain Hunter’s initial decrease in self-efficacy during year one. Hunter described year one as a period of conceptual exposure and uncertainty, particularly as he grappled with integrating phenomena-based instruction and SEPs. Reflecting on this phase, Hunter noted, “I wondered last year, am I going to do this again? But I feel like I wasn’t quite at a point when I knew that if I exited this course, I would be incorporating everything from it” (interview).

By contrast, year two was characterized by increased comfortability with teaching engineering and intentionality, which coincided with notable gains in self-efficacy. Hunter attributed this growth to repeated engagement with the engineering design process across multiple lessons, explaining, “Since I had two lessons last year and three lessons this year, going through the steps of the process of engineering… I feel like I was just getting comfortable with the process and the steps" (interview). He emphasized that this familiarity allowed his confidence to 'accelerate' in year two as instructional components began 'falling into place.'

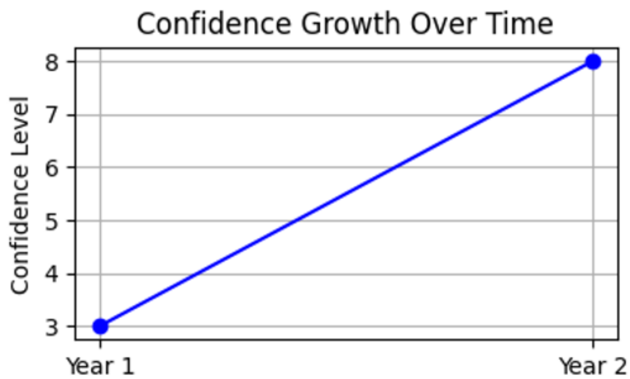
Hunter also highlighted the role of instructional tools in supporting his learning and engineering teaching self-efficacy. He described the CRED lesson framework as a turning point, stating, "When I incorporated the lesson and you guys had the lesson plan template and I could see me using it, that's when my learning started" (interview). Over time, this structure enabled Hunter to expand beyond basic implementation to more sophisticated instructional moves, including data collection, mathematical reasoning, and student self-analysis—areas he identified as initial challenges: "Last year I was just getting comfortable… and now this year I can see aspects that I can add more to the data collection and even self-analysis and the math aspect" (interview).

Participation in the PLC sessions also contributed to shifts in Hunter's engineering teaching self-efficacy. Hunter described breakout room discussions as particularly impactful, noting that "seeing how everybody's interpretations of what they conducted in their classrooms were different" (interview) helped situate his own practice within diverse contextual constraints. Comparing how various rural teachers implemented engineering in their classrooms allowed him to reframe what was possible within his rural setting, reinforcing that meaningful engineering instruction could take many forms, from "building things with popsicle sticks and hot glue" (interview) to large-scale outdoor projects. Taken together, these findings suggest that initial exposure to engineering instructional practices may have temporarily suppressed Hunter's engineering teaching self-efficacy as he confronted the complexity of engineering instruction. However, sustained PL, repeated enactment, and contextualized support appeared to facilitate longer-term growth in his self-efficacy.

5.9. Case 9: Laura

Survey and interview data indicated a complex but overall positive pattern of change in Laura's engineering teaching self-efficacy across the two years of PL. T-STEM self-efficacy scores showed an initial pre-PL score of 4.00, followed by a slight decrease at the end of year one (3.82) and stability at the end of year two (3.82). However, immediate post-PL survey scores increased in both years (Year 1: 4.36; Year 2: 4.09), suggesting short-term gains in self-efficacy associated with PL engagement. Although end-of-year scores returned to baseline levels, the confidence graph (e.g. see Figure 6) reflected strong positive shifts overall, particularly following PL sessions.

Figure 6. Laura's confidence graph



Qualitative data complicated and contextualized the quantitative findings. Despite fluctuations in survey scores, Laura consistently described substantial growth in her self-efficacy over time. Reflecting on her experience, Laura stated, "Over the past two years, my confidence in teaching STEM—especially science and engineering—has grown significantly" (interview). She attributed this growth to cohort support, hands-on experiences, and collaboration, explaining that these opportunities helped her gain "practical strategies for teaching STEM" (interview) and develop "a deeper belief in my ability to lead in this space" (interview).

Early in the PL experience, Laura described feelings of uncertainty, particularly around engineering instruction. She recalled, "That first week, the first year, I was like, oh my goodness. I don't know, I felt a little nervous and wasn't sure where things were going to go" (interview). However, she noted that her self-efficacy increased rapidly following initial implementation: "After the first doing the engineering lesson and the other one, I was more confident with just all of it" (interview). By year two, she described feeling increasingly comfortable participating in PL sessions and sharing ideas with peers, stating, "This year, I felt even more confident during the meetings and I was more confident with sharing my ideas… it feels like each time it's just the steps keep going up" (interview).

Mastery experiences in the classroom were a particularly powerful source of Laura's engineering teaching self-efficacy. Laura pointed to improved student outcomes as evidence of her growing efficacy, noting that her students "scored higher than any of my classes previous to that on the state science test" (interview). She described this as 'a big deal' and linked it directly to increased professional opportunities, including being asked by her principal to teach science and engineering across two grade levels. This expanded role allowed her to build on prior lessons and observe longitudinal student growth, which she described as "very interesting seeing how much they had learned since we started that whole NGSS process" (interview).

Participation in the PLC also emerged as a key support for Laura's engineering teaching self-efficacy. Laura emphasized the importance of breakout groups and peer collaboration, particularly given her rural context: "A lot of times you don't have another person to have those ideas that you share with. So, it's given that support" (interview). Hearing others' ideas and implementations appeared to reduce isolation and reinforce her confidence in adapting engineering instruction to her own rural setting.

Instructional resources introduced through PL further supported her sense of efficacy. She described the CRED lesson framework as instrumental in helping her design her own instruction: "They've helped me make up my own lessons when I want to make sure I'm hitting the points… so you don't have to reinvent the wheel" (interview). She also described creating a classroom wall aligned with crosscutting concepts and cause-and-effect relationships, noting, "I feel like I'm more confident all the time and where I want to go with it" (interview). Collectively, these findings suggest that while Laura's self-efficacy scores exhibited fluctuation across time points, her qualitative accounts revealed sustained growth in engineering teaching self-efficacy.

6. Discussion

This study examined how elementary teachers' engineering teaching self-efficacy developed over time through sustained participation in a PL program grounded in collaborative enactment and reflection. Findings across nine cases underscore the *multifaceted, individualized, and often non-linear nature of self-efficacy development*, while also revealing consistent patterns aligned with Bandura's four primary sources of self-efficacy: (a) mastery experiences; (b) vicarious experiences; (c) social persuasion; and (d) physiological and affective states [1]. Together, these findings suggest that engineering teaching self-efficacy is not simply developed through exposure to content or strategies, but through carefully designed PL experiences that engage multiple efficacy sources over time.

6.1. Mastery Experiences as a Source of Engineering Teaching Self-Efficacy

Consistent with Bandura's theory, *mastery experiences emerged as an influential source of sustained self-efficacy growth* across cases. Teachers whose self-efficacy increased most substantially over the two-year period (e.g., Macey, Sebi, Brielle, Hunter, Laura) attributed their confidence gains to repeated opportunities to design, implement, and refine engineering lessons with students. These mastery experiences were not limited to successful outcomes; rather, they often involved navigating challenges, revising lessons, and persisting through initial frustration.

Importantly, several teachers experienced *temporary declines in self-efficacy immediately following early enactment* (e.g., Andrew, Greta, Hunter), suggesting that confronting the complexity of engineering instruction initially disrupted confidence. However, when teachers were afforded additional opportunities to re-teach lessons with more time, clearer constraints, or stronger instructional scaffolds, their self-efficacy rebounded and ultimately surpassed baseline levels. This pattern aligns with prior research demonstrating that early struggles can undermine self-efficacy unless teachers are supported in transforming unsuccessful attempts into mastery experiences through reflection and re-enactment [28], [29].

Across multiple cases, mastery experiences were further strengthened when teachers observed *positive student outcomes*, including improved engagement, deeper reasoning, and, in some cases, higher achievement. These outcomes functioned as concrete evidence of instructional competence, reinforcing teachers' beliefs in their capacity to teach engineering effectively and motivating continued implementation.

6.2. Vicarious Experiences Through Collaborative Professional Learning Communities

Vicarious experiences played a critical role in shaping teachers' engineering teaching self-efficacy, particularly through *PLC and ELC interactions, breakout room discussions, and video-based reflections.* Teachers consistently described learning from peers who were implementing similar engineering tasks in diverse rural contexts, which helped them recalibrate expectations and envision multiple pathways for successful enactment.

Due to the teachers' rural teaching contexts, seeing their peers succeed with limited resources was especially impactful, reinforcing Bandura's assertion that vicarious experiences are most influential when individuals perceive models as similar to themselves. Across cases, vicarious learning helped teachers reframe engineering instruction as adaptable, reducing perceived barriers and expanding teachers' sense of what was possible within their own classrooms.

These findings extend prior research on teacher PL by highlighting the importance of *structured opportunities for cross-contextual comparison*, rather than unstructured sharing alone [30], [31]. Vicarious experiences were most powerful when embedded within reflective dialogue that allowed teachers to translate observed practices into actionable instructional changes.

6.3. Social Persuasion Through Feedback, Validation, and Professional Recognition

Social persuasion also emerged as a significant contributor to self-efficacy development, particularly when feedback was *specific, credible, and grounded in classroom evidence*. Video-based reflection activities in the ELC were especially influential to teachers' developing self-efficacy, as they allowed teachers to receive affirmation not only from facilitators but from peers who recognized evidence of student engagement in the SEPs.

Teachers frequently described moments of professional validation—realizing that students "knew what they were doing" or that lessons "didn't fall apart as badly as expected"—as pivotal in reshaping their self-perceptions. In several cases, social persuasion amplified the effects of mastery experiences by helping teachers reinterpret classroom outcomes more positively. Rather than viewing imperfections as failure, teachers began to see them as part of the iterative engineering process.

Beyond peer feedback, institutional recognition (e.g., being asked to teach additional grade levels or support colleagues) further reinforced teachers' self-efficacy. This finding aligns with research indicating that social persuasion is most effective when it confirms observable competence and is tied to authentic professional roles [1], [32].

6.4. Physiological and Affective States: From Anxiety to Productive Discomfort

Teachers' emotional and physiological responses to teaching engineering shifted substantially over time. Early stages of PL were frequently characterized by anxiety, nervousness, and uncertainty, particularly among teachers with limited prior engineering teaching experience. These affective states were often associated with early dips in self-efficacy, reinforcing Bandura's claim that emotional arousal influences efficacy judgments.

However, teachers' affective responses evolved from anxiety to *productive discomfort*, and eventually to confidence and enjoyment. Multiple teachers (e.g., Sebi, Greta, Laura) described becoming more comfortable with ambiguity, more willing to admit uncertainty to students, and more open to student-driven inquiry. In several cases, this emotional shift coincided with pedagogical changes, such as giving students more time to struggle productively or emphasizing sensemaking over correctness.

Notably, for some teachers (e.g., Hannah, Olivia), self-efficacy growth was less about increasing confidence levels and more about *reframing their understanding of engineering instruction*, particularly its integration with science and relevance to students' local contexts. These findings suggest that affective and cognitive shifts are deeply intertwined in self-efficacy development, especially for experienced teachers whose confidence is already relatively high [33].

7. Conclusions and Next Steps

Collectively, these findings suggest that *effective engineering-focused PL must intentionally engage all four sources of self-efficacy over time*, rather than assuming efficacy will develop through exposure alone. While short-term gains in engineering teaching self-efficacy were evident immediately following PL sessions, sustained growth depended on repeated classroom enactment, opportunities to learn from peers, meaningful feedback, and support for navigating emotional challenges.

Importantly, fluctuations in engineering teaching self-efficacy should not be interpreted as failure. Instead, they may signal productive engagement with increasingly complex instructional practices. PL designers should anticipate and normalize these fluctuations, providing structured opportunities for reflection, re-teaching, and collaborative sensemaking.

By foregrounding mastery, vicarious learning, social persuasion, and affective support, the PL program examined in this study supported not only growth in engineering teaching self-efficacy but also deeper shifts in instructional practice and professional identity. These findings contribute to the growing body of literature positioning self-efficacy as both an outcome of PL and a mechanism through which sustained instructional change is achieved. Although the sample was small, this study advances new insights into sources of engineering teaching self-efficacy, illustrating the importance of longitudinal, multi-source research in capturing the dynamic process of teacher learning and development.

Acknowledgements

Research presented is based on work supported by the National Science Foundation under DRK-12 Award #2201249. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] A. Bandura, *Self-efficacy: The exercise of control*. W. H. Freeman, 1997.

[2] J. A. Yoon, J. S. Evans, and S. Strobel, "Validation of the teaching engineering self-efficacy scale for K–12 teachers: A structural equation modeling approach," *J. Eng. Educ.*, vol. 103, no. 3, pp. 463–485, 2014.

[3] S. H. Hsu, C. A. Purzer, and M. Cardella, "Elementary teachers' views about teaching design, engineering, and technology," *J. Pre-Coll. Eng. Educ. Res.*, vol. 1, no. 2, pp. 31–45, 2011.

[4] M. J. Banilower, E. R. Smith, I. R. Weiss, and A. M. Malzahn, "The impact of professional development on K–12 teachers' engineering instruction," *Sci. Educ.*, vol. 98, no. 5, pp. 875–901, 2014.

[5] C. Cunningham and M. Carlsen, "Professional development for elementary engineering education: A systematic review," *J. Pre-Coll. Eng. Educ. Res.*, vol. 4, no. 1, pp. 1–14, 2014.

[6] National Academy of Engineering and National Research Council, *Engineering in K–12 education: Understanding the status and improving the prospects*. National Academies Press, 2009.

[7] J. J. Kitchen, A. E. Sonnert, and P. M. Sadler, "The impact of rural context on access to STEM and engineering education," *Res. Sci. Educ.*, vol. 48, no. 2, pp. 357–379, 2018.

[8] National Science Board, *Elementary and secondary mathematics and science education*. Alexandria, VA, USA: National Science Foundation, 2018.

[9] E. R. Haverly, A. J. Kranzfelder, and C. A. Moore, "Barriers to elementary engineering instruction: Teachers' perspectives from rural schools," in *Proc. ASEE Annu. Conf. Expo.*, 2019.

[10] J. G. Whitworth and S. L. Chiu, "Rural elementary teachers' experiences integrating engineering into science instruction," *J. Pre-Coll. Eng. Educ. Res.*, vol. 5, no. 2, pp. 22–35, 2015.

[11] D. Menon, J. R. Wieselmann, S. Haines, and S. Asim, "A Meta-Synthesis of the Literature on Science & Engineering Teaching Self-Efficacy: Current Gaps and Future Research Directions," *Journal of Science Teacher Education*, vol. 35, no. 5, pp. 480–503. 2024.

[12] E. J. Kang, M. J. McCarthy, and C. Donovan, "Elementary Teachers' Enactment of the NGSS Science and Engineering Practices," *Journal of Science Teacher Education*, vol. 30, no. 7, pp. 788–814. 2019.

[13] J. H. Sandholtz, and C. Ringstaff, "Reversing the Downward Spiral of Science Instruction in K-2 Classrooms," *Journal of Science Teacher Education*, vol. 22, no. 6, pp. 513–533. 2011.

[14] J. H. Sandholtz, and C. Ringstaff, “Inspiring Instructional Change in Elementary School Science: The Relationship Between Enhanced Self-efficacy and Teacher Practices,” *Journal of Science Teacher Education*, vol. 25, no. 6, pp. 729–751. 2014.

[15] R. Hammack, and T. Ivey, “Examining Elementary Teachers’ Engineering Self-Efficacy and Engineering Teacher Efficacy,” *School Science and Mathematics,* vol 117, no. 1-2, pp. 52-62. 2017.

[16] T. Porter, M. E. West, R. L. Kajfez, K. L. Malone, and K. E. Irving, “The Effect of Teacher Professional Development on Implementing Engineering in Elementary Schools,” *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 9, no. 2. 2019.

[17] K. Sargianis, S. Yang, and C. Cunningham, “Effective Engineering Professional Development for Elementary Educators,” *ASEE Annual Conference & Exposition Proceedings*, 2012.

[18] C. Crawford, C. Obenland, and C. Nichol, “An Analysis of the Effect of Long-Term Professional Development on Teacher Engineering Self-Efficacy and Its Impact on Classroom Instruction,” *The Journal of STEM Outreach*, vol. 4, no. 1. 2021.

[19] K. Gardner, D. Glassmeyer, and R. Worthy, “Impacts of STEM Professional Development on Teachers’ Knowledge, Self-Efficacy, and Practice,” *Frontiers in Education*, vol. 4, no. 26. 2019.

[20] T. Ivey, N. M. Colston, J. Thomas, and J. Utley, “Integrated engineering in elementary education: tackling challenges to rural teacher training,” *ASEE Conference & Exposition, New Orleans, LA, USA.* 2016.

[21] National Academies of Sciences, Engineering, and Medicine (NASEM), *K-12 STEM Education and Workforce Development in Rural Areas*. The National Academies Press. 2025.

[22] S. Rivera, I. Kiiza, K. Kavanagh, J. DeWaters, B. Galluzo, and R. Ramsdell, R, “Challenges & opportunities for STEM teachers in rural schools: a case study,” *Thresholds in Education,* vol. 46, no. 1, pp. 420–432. 2023.

[23] J. Utley, T. Ivey, R. Hammack, and K. High, “Enhancing Engineering Education in the Elementary School,”, *School Science and Mathematics,* vol. 119, no. 4, pp. 203-212. 2019.

[24] F. Bowman, B. Klemetsrud, E. Ozturk, J. Robinson, and E. Lacina, “Impact of Professional Development in Culturally Relevant Engineering Design for Elementary and Middle School Teachers,” *ASEE Conferences*. 2024.

[25] A. Unfried, A. Rachmatullah, A. Alexander, and E. Wiebe, “An alternative to STEBI-A: Validation of the T-STEM science scale,” *International Journal of STEM Education*, vol. 9, no. 1, p. 24. 2022.

[26] S. B. Merriam, *Case study research in education: A qualitative approach.* Jossy-Bass Publishers. 1988.

[27] J. Saldaña, *The coding manual for qualitative researchers*. SAGE. 2021.

[28] D. Palmer, "Sources of self-efficacy in a science methods course for primary teacher education students," *Research in Science Education,* vol. 36, no. 4, pp. 337–353. 2006.

[29] M. Tschannen-Moran, and A. W. Hoy, "The differential antecedents of self-efficacy beliefs of novice and experienced teachers," *Teaching and Teacher Education,* vol. 23, no. 6, pp. 944–956. 2007.

[30] E. Wenger, *Communities of practice: Learning, meaning, and identity.* Cambridge University Press. 1998.

[31] J. A. Ross, and C. D. Bruce, "Professional development effects on teacher efficacy: Results of randomized field trials," *The Journal of Educational Research,* vol. 101, no. 1, pp. 50–60. 2007.

[32] C. D. Bruce, I. Esmonde, J. Ross, L. Dookie, and R. Beatty. "The effects of sustained classroom-embedded teacher professional learning on teacher efficacy and related student achievement," *Teaching and Teacher Education,* vol .26, no. 8, pp. 1598–1608. 2010.

[33] A. Bandura, "Perceived self-efficacy in cognitive development and functioning," *Educational Psychologist*, vol. 28, no. 2, pp. 117-148. 1993.