A Deep Dive in Preservice Teacher Self-Efficacy Development for Teaching Robotics (RTP)

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Abstract: Nationwide K–6 engineering and coding standards have made it increasingly important to prepare elementary preservice teachers (PSTs) to teach these subjects confidently and effectively. Robotics, which combines coding and engineering, provides a rich context for developing PSTs' expertise and self-efficacy. This study builds on prior work in which PSTs in an instructional technology course collaborated with undergraduate engineering students to co-teach robotics lessons to fifth graders. Using a multiple-embedded case study approach, we examine how the interactions and teaching roles within these partnerships influenced PSTs' teaching self-efficacy. Drawing on reflections, lesson recordings, surveys, and interviews, we present the cases of three PSTs—Lisa, Madison, and Kayla—who experienced varying levels of partner support and student engagement. Lisa and Madison were both compelled to lead robotics instruction due to perceived lack of support from their engineering partners, yet they experienced contrasting outcomes: Lisa struggled with disengaged students and malfunctioning robots, which diminished her self-efficacy, while Madison's success with highly engaged students bolstered hers. Kayla, in contrast, developed self-efficacy over time through a productive partnership with a supportive engineering student. These cases highlight the complex relationship between partner dynamics, teaching roles, perceived success, and self-efficacy development. Implications for supporting PSTs in engineering-integrated experiences are discussed.

Introduction

Nationwide engineering and coding standards in K-6 curriculum [1], [2] make instruction in these subjects essential for elementary teacher preparation. Along with content and pedagogical knowledge, preservice teachers (PSTs) need a belief in their ability to teach, also known as teaching self-efficacy [3], [4]. Accordingly, there is a need to understand how PSTs develop teaching self-efficacy in these areas [5], [6].

In earlier related research, the authors partnered PSTs in an instructional technology course with undergraduate engineering students in an electromechanical systems course to teach robotics lessons to fifth graders. Teaching robotics was selected as an ideal context for PSTs to gain relevant experience because robotics fuses coding and engineering and growing evidence supports it as a powerful approach to STEM learning and self-efficacy development [7], [8], [9]. PSTs' relationships with their engineering partners and interactions with the fifth graders exerted a meaningful influence on their satisfaction with the project and their teaching self-efficacy [10], [11]. PSTs who were more satisfied with their partners tended to rate the project more highly [12]. PSTs' satisfaction was often tied to their perceptions of workload, with PSTs in more balanced relationships feeling more satisfied. Interestingly, PSTs' satisfaction with their engineering partner(s) did not have a direct relationship with their self-efficacy [11]. Instead, it was mediated by their teaching roles and perceived success in teaching the fifth graders. PSTs who were satisfied with their engineering partners tended to feel supported. This support encouraged some PSTs to embrace engineering teaching roles and develop self-efficacy throughout the project. However, other PSTs allowed supportive engineering partners to dominate the engineering teaching roles, and consequently developed less teaching self-efficacy. PSTs who were unsatisfied with their partners tended to feel unsupported and pressured to lead the engineering instruction. In these cases, the PSTs' perceptions of their success teaching the fifth graders became a powerful factor influencing their teaching self-efficacy. PSTs who felt successful teaching their students reported higher levels of teaching self-efficacy than PSTs who felt less successful.

In this paper, we elaborate on our initial findings, examining the cases of three PSTs to better understand how their interactions with their engineering partners and fifth-grade students influenced the development of their teaching self-efficacy. Utilizing a myriad of data sources (e.g., reflections, lesson recordings, surveys, interviews), we present in-depth studies of Lisa, Madison, and Kayla (pseudonyms) using a multiple-embedded case study approach [13]. These three cases were selected because they represent a range of outcomes in terms of the development of the PSTs' self-efficacy and the success of the robots produced by the team. Lisa and Madison's cases demonstrate contrasting outcomes for PSTs who were compelled to lead the robotics instruction in their teams because they felt unsatisfied and unsupported by their engineering partners. Lisa described her students as "shy" to interact and they did not produce functioning robots which hampered the development of her self-efficacy. In contrast, Madison's highly engaged students' successful performance bolstered her self-efficacy. The third case, Kayla's, illustrates a PST's positive journey collaborating with an engineering partner with whom she was very satisfied. Her interactions with a highly invested partner supported the development of her teaching self-efficacy over the course of the project. Together these three cases provide an examination of the connections between the PSTs' relationships, perceptions of success, and teaching self-efficacy. The purpose of this paper is to describe the three cases in detail, providing a deep dive into the experiences of the PSTs and uncovering the lesson events and interactions that prompted them to consider their capabilities for teaching engineering and coding. This intimate account allows teacher educators to see how a teacher preparation experience influenced three individual PSTs' beliefs about themselves. In a separate paper, we provide a detailed cross analysis of the three cases in order to draw conclusions about the design of the intervention and strategies for PST preparation to teaching engineering and coding generally.

Background

Self-efficacy develops through social interactions and self-reflection and is influential in determining outcomes [3]. Bandura [14] named four sources of self-efficacy: verbal persuasion, vicarious experiences, physiological arousal, and mastery experiences. These sources provide a helpful framework for understanding how self-efficacy develops. Verbal persuasion includes feedback from trusted sources, such as instruction during teacher preparation [4]. Vicarious experiences occur when individuals observe others' successes, while physiological arousal involves emotional states influencing confidence. Experiencing a positive emotion can suggest self-confidence, whereas experiencing a negative emotion can suggest anxiety about one's ability [14]. Mastery experiences—firsthand successes—are the most impactful for building self-efficacy [4]. Although both are important to self-efficacy development, success in understanding how to do something, or cognitive content mastery [15], is distinct from enactive mastery, which is achieved only during success engaging in a particular situation. Accordingly, teachers can only experience enactive mastery in an authentic teaching situation [4]. Teachers' self-efficacy evolves as they encounter challenges and successes in real teaching contexts.

Research often emphasizes how teacher self-efficacy impacts student outcomes but less so how student behavior shapes teacher self-efficacy. Positive student engagement can bolster teachers' confidence, whereas negative interactions may trigger stress and lower self-efficacy, especially for novice teachers [16-18]. Supportive environments and positive feedback from mentors and colleagues can also enhance novice teachers' self-efficacy [19-20]. For example, collaborating within a successful team fosters collective self-efficacy—the shared belief in a group's ability to succeed [21]. It is important for teacher educators to understand how interactions with students and peers can influence elementary PSTs' teaching self-efficacy. PSTs can interact with K-6 students during traditional field placements and also in non-traditional settings like afterschool clubs where they are likely to find highly motivated students. Afterschool programs can also afford PSTs the opportunity to collaborate with peers in teams under the close supervision of their instructors. Teaching a small number of highly engaged students in a low-stress, collaborative, and supportive environment can result in mastery experiences that strengthen their self-efficacy [22-23].

This study explores how PSTs' self-efficacy developed through co-teaching robotics with engineering students in an afterschool program. Engineering students were selected as collaborators because they were expected to have interest and prior knowledge in engineering and coding that they would be able to share with the PSTs and elementary students. Furthermore, to meet accreditation standards, engineering faculty are increasingly expected to provide their students with interdisciplinary experiences to prepare them for such encounters in the workplace. Prior research examining the effects of partnering engineering students with in-service teachers [24] and preservice teachers [25][10][26] found positive benefits for both the engineering students and the teachers, including increases in PST self-efficacy for teaching engineering [27][28].

Given the growing need for elementary teachers to teach engineering and coding [29-30], and the fact that only 3% of elementary teachers in the U.S. feel confident teaching engineering [31], teacher educators must learn how to help PSTs develop teaching self-efficacy for engineering and coding [31-32]. Teachers with high self-efficacy are more open to new teaching methods [33], while low confidence in teaching engineering remains a major barrier to the integration of engineering in P-6 instruction [34-35]. The need for teacher educators to help elementary PSTs develop teaching self-efficacy is paramount.

To support teachers' ability to integrate engineering and coding in elementary instruction, teacher educators must design PST learning experiences rich in sources of teaching self-efficacy. Potential mastery experiences, such as the opportunity to teach engineering lessons to students, can be especially powerful influences on PST beliefs. Successful experiences teaching engineering have been shown to significantly improve PSTs' self-efficacy [35-36]. Cognitive content mastery (e.g., learning how to engineer a solution or develop a lesson plan) and vicarious learning—such as observing engineering lessons or co-teaching—also contribute to efficacy development [15,28,37]. However, the influence of social interactions within a co-teaching context is not well understood, limiting effective design of these experiences.

This study explores the research question, *How does PSTs' self-efficacy for teaching engineering and coding develop through co-teaching robotics with engineering students in an afterschool program for fifth graders?* This socially rich environment offers insights into how mastery experiences, vicarious experiences, social persuasion, and emotional responses interact to shape teaching self-efficacy. Understanding these dynamics can guide teacher educators in creating collaborative experiences that foster PSTs' professional growth.

Study Context

As part of an NSF-funded initiative, this study paired PSTs in an instructional technology course with engineering students in an electromechanical systems course to teach robotics to fifth graders in the context of an afterschool technology club that met during the college students' class times. PSTs were paired with one or two engineering students to lead two fifth graders in a robotics project. The teams were tasked with designing, building, and coding bio-inspired COVID-companion robots that utilized lights, sound, movement, and sensing to interact with a user. Each team developed a vision for their COVID companion with each participant constructing their own robot.

The PSTs and engineering students prepared for teaching the fifth graders during four collaborative class meetings. Here they engaged in team building, learned to program the components (LEDs, speakers, servo motors, sensors) of their Hummingbird Robotics Kits®, and designed a simple mechanism to enable robotic movement. Teams met once outside of class to complete a collaboration plan enumerating their goals and communication protocols and plan their lesson for the fifth graders.

As the project occurred during the COVID-19 pandemic, the course meetings and club sessions were conducted entirely via Zoom with all participants working remotely, typically from their homes. The robotics instruction for the fifth graders occurred over five, 1.5-hour sessions. The course instructors started the Zoom sessions with all participants included. The teams then met in breakout rooms to work on their robots while the two instructors and three teaching assistants moved between rooms to assist as needed. All of these sessions occurred during the college students' class time. The project culminated in a virtual showcase to which the children's families were invited.

Methods

We use a multiple-embedded case study approach [13] to explore how PSTs' social interactions within a multi-day robotics lesson taught to fifth graders, and their reflections on those interactions, influenced the development of their teaching self-efficacy. We selected three cases, Lisa, Madison, and Kayla (pseudonyms), to represent the varying levels of satisfaction PSTs expressed with their engineering and fifth-grade partners and the varying levels of success within the teams' robots. The difference in outcomes allowed us to examine connections between these factors and the PSTs' self-efficacy. Although undergraduate engineering students and fifth graders participated in the project and their interactions with the PSTs are discussed, their internal experiences were not investigated as part of this study. Instead, each case is bounded by the perceptions of the PST [38]. Furthermore, while the PSTs participated in training activities prior to teaching the robotics lessons to the fifth graders, these preparation experiences and corresponding interactions with their course instructor are not examined as part of this study. These activities or interactions are only addressed if PSTs specifically mentioned them in their reflections or interviews. All participants consented to participate in the study.

Multiple data sources were collected, analyzed, and triangulated [39] to understand the PSTs' experiences, including both self-report and observational data [40]. These include PSTs' class assignments, responses to team member effectiveness surveys, short-answer end of course reflections, follow-up interviews, and Zoom session recordings. Sample items are listed in Table 1. Through an iterative, holistic analysis process, the authors examined the data and reconstructed each case [39,41]. To begin this process, all the data from each case was collaboratively coded by a team of two researchers using a codebook with apriori themes associated with PST roles, confidence, affect, and interactions with engineering and fifth-grade partners to identify any data related to PST self-efficacy. These datasets were then compiled to produce a detailed description of each PST's behavior and beliefs throughout the project. The descriptions included researcher observations from the Zoom recordings as well as the PSTs' own accounts of their experiences from their surveys, assignments, and reflections. The researchers conducted follow-up interviews with each PST several months after the project to learn more about the PSTs' backgrounds and perceptions of their experiences and to confirm their interpretations of the data, thereby enhancing the trustworthiness of the findings [42]. The accounts of PSTs' behaviors and beliefs were then analyzed in accordance with the definition of teaching self-efficacy and associated four sources [4,14], to consider how their social interactions and reflections on those interactions related to the development of PSTs' teaching self-efficacy, and organized accordingly. The resulting narratives were generated using the PST's own words and descriptions of lesson events from the Zoom recordings as much as possible, but they also included the researchers' inferences based on observations across all data sources.

Table 1. Sample Items

Data Source	Sample items
Class assignment	• Describe how you helped 5th grade students at the club learn robotics and coding. (Prompt from the Technology Portfolio, a class assignment)
Team member effectiveness surveys	• I am satisfied with my present teammates. • I am pleased with the way my teammates and I work together. (Likert scale items with option for open comment)
End of course reflection	• Was your collaboration with your engineering/education partner(s) effective? Did you benefit from working with him/her/them? Were you satisfied with your partnership experience overall? Please explain your answers. • How confident are you in your ability to teach an

	engineering lesson in your future classroom? What specific factors have impacted your confidence?
Follow-up Interview	● How did your elementary students' interest affect your own attitude toward the project and toward engineering more broadly? ● How would you characterize the success of your lesson? On a scale of 1 to 10? Follow up: What are you considering when you rate its success? In other words, how are you defining success?

To explore the influence of the social interactions that occurred during the robotics lessons, we focused primarily on observable lesson events, either as they were described by the PSTs or witnessed in the Zoom recordings. We begin with a description of the people within the PST's team and the extent to which they engaged in the project activities. We next describe the lesson preparation and teaching actions taken by the PST and the product-based lesson outcomes. Following this, we chronicle interactions between the PST and teammates or instructor, that are likely to have influenced the PSTs' teaching self-efficacy, and thus serve as sources of teaching self-efficacy. These are organized by the four sources of self-efficacy described by Bandura [14]: verbal persuasion, vicarious experience, physiological arousal/affect, and mastery experience.

To examine how each PST's reflection on their experience influenced their self-efficacy, we ventured away from observable behaviors and into the personal thoughts and beliefs of each PST. To describe the sensemaking and attitude adoption that occurred within the PSTs' minds, we use the reported thoughts and feelings of each PST as much as possible, but we also include inferences based on what we observed in the videos, heard in the interviews, and read in the reflections. We start with an account of how each PST interpreted their teaching task, focusing on the PST's expressed goal for their sessions. This leads to an examination of how each PST evaluated their success in reaching those goals, including an account of the contextual factors that supported or hindered their ability to teach, as well as their evaluation of their success in teaching their fifth-grade partners. We discuss each PST's self-efficacy for teaching engineering and coding and the PSTs' interest and goals in teaching engineering and coding in the future.

Findings

This study used three cases to examine how PSTs' experiences teaching robotics to fifth graders alongside engineering students shaped the development of their teaching self-efficacy for engineering and coding. To present our findings, we discuss each PST's case individually, considering the influence of both the social interactions that occurred within the context of the lesson and the PST's cognitive processing of their experiences. While we present the findings of these two realms of influence separately as part of our attempt to uncover how self-efficacy is shaped and may be influenced, we acknowledge that there is considerable overlap and interaction between the social interactions in which an individual participates and that individual's interpretation of those interactions. We begin each case with an introduction to the PST. This provides context for understanding both the PST's interactions with their teammates and their reflection on the lesson events.

Case 1: Lisa

Lisa is a friendly and outgoing White female in her mid-20s studying elementary education. She prides herself on her ability to communicate and strives to be "kind to everyone." She acknowledged that she can become frustrated if others do not reciprocate. She recalled struggling as a student during her own K-12 school experience and shared that people were not always kind to her. As a result, she is particularly passionate about creating an inclusive classroom where kids will not be "afraid to open up" and can be "friends with everyone." This focus on the importance of a safe and inclusive discourse-rich environment was mirrored in her own description of herself as someone who "loves group projects and… talking in class," as well as her experience during the project where she actively sought out opportunities to share stories with both her instructor and her classmates.

At the time of the study, Lisa was teaching preschool and had plans to teach at the lower elementary level, ideally kindergarten. Before joining the elementary education program, Lisa received a degree in theater. During this program, she worked with middle and high school students, and although she said she did not realize it at the time, she now sees how her efforts in set design required the use of the engineering design process. She also described how the programming she did for a course on light and sound design was not entirely dissimilar from the coding that she did during the project. Despite these connections, Lisa still felt she entered the course with "zero confidence" in engineering and coding and believed she "never engineered or coded anything before this course."

The Influence of Lisa's Social Interactions on her Teaching Self-Efficacy

Lisa was partnered with two engineering students, Felicity (Black female) and Gerry (White male), and two fifth graders, Jalisa and Nevaeh (Black females). Lisa was present and actively engaged at all sessions. The other team members' attendance (i.e., fifth graders, engineering partners) was less consistent. The engineering partners adopted a consultant-type role, assisting as required, otherwise speaking minimally. During the sessions, team members frequently worked independently on their robots, conferring as needed to address issues.

Lisa reported dissatisfaction with her engineering partners, noting a lack of initiative and investment: "If not directly told when and where to add work, the engineers would not contribute or meet to complete the project." She vented in her reflection, "I guess it was assumed that I was just going to be the one to start every conversation, every Zoom meeting, and every lesson we had with the kids." She found the uneven distribution of effort disheartening and frustrating, noting that the virtual environment "gave them a curtain to hide behind," evidenced by Gerry, who never turned on his camera.

Lisa also discussed difficulty bonding with her fifth graders. Internet issues and shyness prompted them to communicate by typing into the chat window rather than using their cameras and microphones. She explained how "having cameras off was really difficult because it was hard to see whether they actually wanted to be there or not.” Lisa worried about the girls’ interest in engaging with her and considered the role of race in their interactions: “I'm White, and they were both of African American descent… being in a predominantly African American area, it is sometimes a little difficult to talk to someone who doesn't look like you.” Consequently, she waited for them to “open up” rather than asking them to turn on their cameras for fear of making them uncomfortable. Lisa explained that eventually, the girls “came out of their shells” and began turning on their cameras which really “flipped a switch” for her: “when they were actually participating, my confidence went way up.”

As the self-appointed leader and often the only adult present, Lisa set the session agendas and tone. Even when the engineering partners were present, she led the instruction. She and the girls followed the same general plan, with the fifth graders making minor design decisions. She often waited for the girls to ask questions rather than providing pre-planned instruction. This accommodated the girls’ uneven attendance and progress. Although she could adeptly explain how to sequence blocks to produce a given code, Lisa did not feel confident writing code to achieve a desired action and did not want this instructional role. In one Zoom session, she told a teaching assistant, “Gerry should be coming. He's the one who is, like, the coder because… I don't know how to code.”

Lisa started the project with an inquiry-based approach, but when the children suggested complex designs like “a bunny that brings you water,” she urged them to choose the simpler task of pulling tissues (see Figure 1), worrying about her ability to guide them. Lisa migrated toward a more directive style, sharing “mockup design” ideas she thought would be feasible and help the elementary students “reach [their] end goal.”

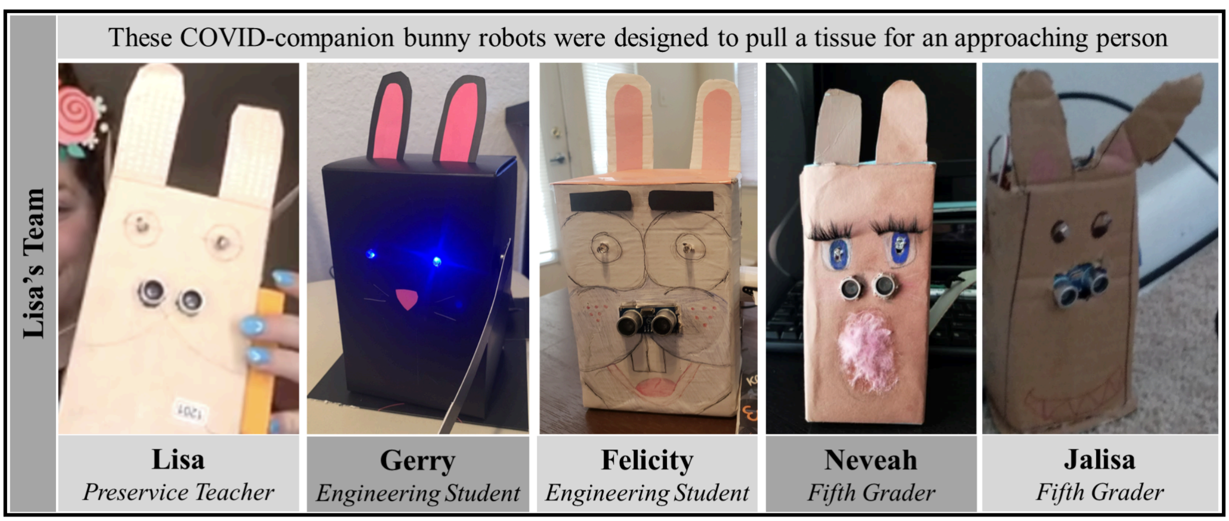

Figure 1. Team Lisa’s Robots

The team’s robots followed similar designs; however, only Felicity’s (engineering student) functioned as intended and met all the established criteria (i.e., responded with lights, sound and movement to a user-initiated stimulus). Lisa explained how her students “gave it their best effort” but “were unsuccessful at creating a function[al] robot.” The problems related primarily to the mechanism the team planned to achieve the desired movement, a tissue-pulling crank, which did not function in any of the robots. Both of the engineering students on her team used a simpler mechanism to move their bunnies' arms.

Sources of Teaching Efficacy Information.

Verbal Persuasion. Lisa did not discuss any incidences of social persuasion emanating from her engineering partners. Instead, she described her instructor as "a lighthouse in the storm," recounting how she helped mediate her team's unhealthy dynamic. She felt validated when her instructor acknowledged the project's difficulty and appreciated her encouragement throughout the process (e.g., "I know this is a difficult process, especially over Zoom, [but] you got this [...], things are going to be okay!"). Alongside the education instructor, Lisa explained that the teaching assistants were also "helpful and encouraging," colloquially characterizing this as "saving [her] butt a bunch of times!"

Vicarious Experience**.** Lisa was unable to benefit vicariously from watching her engineering teammates. Felicity did not finish in time to demonstrate her robot, and Gerry never showed his robot during the Zoom sessions. Furthermore, her engineering partners rarely adopted a teaching role. Lisa did compare her performance to other classmates, noting that her group was not "the only group whose robots didn't work," which she found "very reassuring." This suggests that the class context provided a means for Lisa to assess her competence in comparison to similar peers and that she determined she was not performing lower than most of her classmates.

Physiological Arousal/Affect. Lisa's frustration with her engineering partners was a significant stressor throughout the project. Lisa connected the disappointment she felt to her disposition, explaining she does not like to ask for help: "It's taken me 25 years to be comfortable asking for help… so, when I did ask for help, and wasn't given the help, that was a… big big wave, a big wave of left down."

Lisa went on to describe a sequence of stressful affective states throughout the project. She said that at the onset, she was scared; in the midst of the project, she felt anxiety; and at the conclusion, she was relieved. At the first Zoom session, Lisa felt rejected when her fifth graders did not turn on their cameras or microphones and gave only one or two-word answers when she tried to connect by "sharing [her] life story." She explained that this "scared her" as she thought, "How can I teach if they don't want to be here?" Moving through the sessions, the girls began to turn their cameras and mics on, but Lisa remained anxious. She revealed minor signs of fatigue (e.g., less eagerness, a laissez-faire approach) in later Zoom sessions as she continued to bear most of the instructional burden and faced constant technical challenges. For example, after struggling with the crank mechanism over numerous sessions, Lisa shifted away from the goal of successful robots. When Jalisa (fifth grader) expressed disappointment about a failure, Lisa replied, "That's okay. What matters is that you did it. That's what matters." Lisa conveyed mixed emotions about the project. In her interview, she revealed,

> *I feel I could have done better. I feel as if I let our club kids down because they got to the end of the semester and saw everybody else's projects, and I feel as if everybody else had a much better process than we did. And I wonder what I could have done differently.*

Offsetting this self-doubt, Lisa expressed pride in the girls' perseverance: "Through multiple trial and errors, my fifth-grade partners never gave up on their robots and project."

Mastery Experience. Lisa successfully built and coded robots during the training phase, developing some cognitive content mastery. She was able to explain to the students how they could position kit components to create the tissue-pulling mechanism they envisioned. While neither she nor her fifth grade students were ultimately able to make the mechanism work, Lisa felt that she and her fifth graders learned "a great deal about engineering and coding… through multiple trials and errors," especially as they were all "new to the subject." So, despite difficulty translating her early success with the robots into her lessons with the fifth graders, Lisa's perseverance through a new and challenging teaching task contributed to her teaching self-efficacy.

The Influence of Lisa's Self-Reflection on her Teaching Self-Efficacy

Lisa described the teaching task as very challenging and identified contextual factors exacerbating its difficulty. She explained how the Zoom environment added complexity by limiting her ability to "physically model and show [her] students how to fix, build, code, and create their robot" and to communicate easily and comfortably with teammates. Lisa revisited her frustration with her partners, explaining, "My engineers' lack of effort greatly affected the success of our project." She felt other teams had more committed team members who gave "110%," including not only the engineering partners and the fifth graders but the fifth graders' parents as well. She felt these additional resources, plus more time, would have made a considerable difference in her team's resulting robots.

Lisa's original goal was for each team member to "construct [their robot] and have it work…not like making it pretty or some spectacular thing, but just having it work and having our code work." Lisa also wanted the girls to "feel comfortable" during the sessions. This goal may have taken on more prominence in subsequent Zoom meetings as the team continued to struggle with their robots.

Lisa reported both positive and negative feelings about her success. On the one hand, she decided that she helped her students gain social skills and the tenacity to persist through a challenging project, on the other hand, she readily acknowledged the lack of functionality in her team's robots. She attributed the failure to her team's design process, namely sticking with the tissue-pulling mechanism despite their difficulty implementing it. She questioned whether her own lack of knowledge contributed to their difficulty: "I don't know if that was [from] me not really understanding how to make the project, or my engineers not understanding how to make the project."

Lisa's focus on contextual factors outside of her control, such as the lack of support from her engineering partners, helped her maintain teaching self-efficacy, as did a change in her conception of the teaching task. She pivoted away from the goal of producing functional robots and toward the goal of helping the students feel comfortable in the experience. She also reconsidered her overall goal in the course. Upon reflection, she said the real "motivation for this course" was the opportunity to learn from the experience of "teaching actual students… and try[ing] different [instructional] methods."

Lisa's confidence in engineering and coding influenced her teaching self-efficacy for these subjects. At the end of the course, Lisa said that the project made her "realize how hard it is to engineer and code." Lisa explained that her confidence in both areas began at "zero," but by the end, she felt as if she could "understand and carry [on] a conversation about engineering and coding." Lisa said she felt "way more confident teaching somebody how to build something rather than teaching someone how to code." This mirrors her behavior in the Zoom sessions, where she confidently led the girls in the design and building of the bunny robots but wanted to avoid teaching the coding and requested assistance from her engineering partners.

While Lisa admitted that she was "nowhere close to 100% confident" in engineering and coding, she said she is "able and willing to learn more." She shared that she is "less likely to integrate coding [than engineering] into [her] future classroom" because she feels as if "coding would be too advanced for a kindergartner" and that she "would need more research and time with coding" before being able to confidently teach a lesson. However, she believes the project gave her the confidence to teach an engineering lesson in her future classroom because she was "able to write and create a lesson plan." Lisa also explained that she prefers engineering over coding because she sees its innate connections to the world around her.

Case 2: Madison

Madison is a highly conscientious, reflective, and artistic White female studying early childhood education. She sets high expectations for herself and works diligently to achieve her goals. She described herself as "a planner, through and through." This was evident throughout the course as she was exceptionally well prepared for all the sessions, and her work was consistently thoughtful and carefully constructed. Madison also described herself as assertive, considerate, and someone who cooperates well with others, but overall, said she would not describe herself as talkative. This mirrors her demeanor in the Zoom sessions, where she was pleasant and sociable but goal-focused and in charge.

Madison was raised in a household that valued art, music, and creative writing, and wants to help her future students "channel emotion and creativity through art." At the time of the course, Madison had previous experience learning about and working with young children during her Associate of Science degree, where she obtained a concentration in developmental psychology. However, this project was her first time teaching elementary students, and she had no prior experience in engineering and coding. Even so, Madison saw engineering aligning well with her focus on creativity and having students construct artifacts that represent their learning, highlighting that she wants her students to not only "think critically, but *make* critically" and to see themselves as creators.

The Influence of Madison's Social Interactions on her Teaching Self-Efficacy

Madison was paired with Drake, a Black male engineering student, and two fifth-grade boys, Anthony (White) and Henry (Multiracial). All team members attended the required sessions and interacted positively with cameras and microphones on. The only exception was Anthony, who occasionally switched off his camera or aimed the camera at the top of his head, which Madison attributed to his shyness/nervousness.

Despite amicable interactions, Madison reported being unsatisfied with Drake, citing his minimal involvement and lack of commitment to the project: "I just don't think he is as invested in this project as I am." She found Drake "difficult to reach" and did "not have confidence in his ability to manage [the] team's schedule and progress." Accordingly, she felt obligated to take the lead in preparing and teaching every week. To promote Drake's involvement, Madison would ask him decision-making questions, such as "Should we just keep writing… or download and test [the code]?" This was not entirely successful, as Drake can be seen yawning and struggling to maintain attention in later sessions. Madison was hesitant to push Drake, however, concerned that "asking him to be more involved…would make him resent me as a partner." She wanted to avoid any action that could "negatively affect our working relationship or our interactions with our students." Madison attributed their roles to differences in their personalities and work styles: "I naturally like to take the lead, and Drake naturally likes to follow…this, along with a combination of other factors, solidified our dynamic."

In contrast to her uneasy relationship with Drake, Madison had positive interactions with her two fifth grade students, describing them in her reflection as "endlessly helpful, funny, and a joy to work with." She went on to say that they were "better collaborators than many of the adults" with whom she had collaborated and "were willing to work on their robots outside of [the] club."

Madison set the agenda and confidently delivered nearly all the instruction. She thoroughly prepared for every session, creating elaborate slides, videos, and demonstration materials. She also spent extra time outside of class to improve her coding skills and adapt lesson materials based on issues she believed students might encounter. During the sessions, she consistently monitored the boys' progress. If they got off track, she quickly drew them back in. When issues arose, she was the one to troubleshoot and reassure them when solutions failed.

The team decided to make "Comfort Cat" robots to calm people and help them feel less alone during the pandemic (see Figure 2). When petted, the cat's tail moved from side to side, and music played. An additional mechanism, a tongue, was planned to protrude when an object (e.g., a bowl) approached the cat's mouth. Only Madison successfully achieved this goal. In order to finish in time, Madison directed the fifth graders to abandon the feature when they struggled to build the underlying mechanism. Even without the tongue, the team's robots were successful and met the established criteria of responding to a user with lights, sound and movement. Madison's robot was exceptionally successful: demonstrating a high level of artistry and technical merit (i.e., tongue mechanism) and it won the Audience Choice award among the preservice teachers' robots.

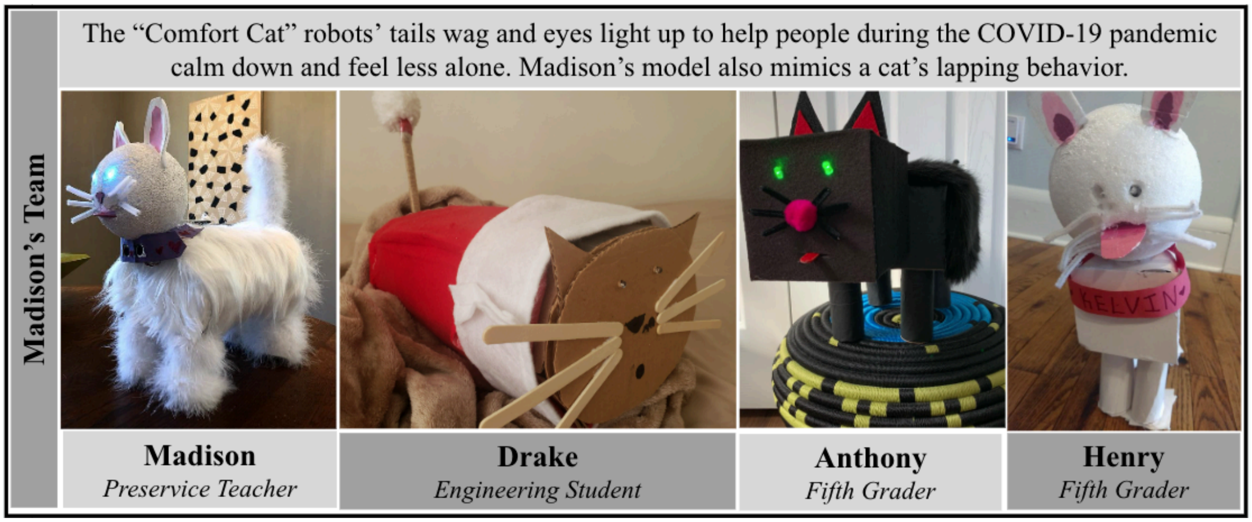

Figure 2. Team Madison’s Robots

Sources of Teaching Self-efficacy Information.

Verbal Persuasion. Madison explained how she gained motivation and confidence from her “instructor’s faith in her.” Madison did not mention receiving encouragement from Drake, but in the sessions, he can be seen listening to her instructions and nodding to express agreement and confirmation. This non-verbal expression may have assured Madison that she was on the right track.

Vicarious experiences. Madison is unlikely to have gained much self-efficacy through the vicarious experience of her engineering teammate. Drake did not share his robot during the sessions and engaged in very little direct teaching. Madison seemed to gain much more confidence from other sources of self-efficacy.

Physiological Arousal/Affect. Madison’s relationship with Drake was a source of some distress. She expressed disappointment in his low investment and concern over trying to involve him without having to rely on his assistance. This anxiety does not appear to have negatively influenced her self-efficacy, however. In her reflection, she explained, “I wouldn’t say that I struggled to carry the weight of the team. At no point did I feel that I would not be successful without Drake.”

Despite the tension of navigating interactions with Drake, Madison appeared untroubled in the sessions. She laughed at Henry’s jokes and acknowledged the children’s accomplishments. When Henry successfully downloaded his first tri-LED code, Madison readily congratulated him: “Oh, you did it! You just downloaded your first code into the micro:bit. You should feel very proud of yourself.” Madison also expressed pride in herself and her team. She posted their robots and awards on her personal portfolio website. In her reflection, she explained “how proud [she] was of [her students], how impressed [she] was with their performance, patience, and determination.” Madison seemed impressed by her own facility for robotics: “I was surprised to find how easy it was to discuss these [coding] concepts." Even the failed tongue mechanism led to a feeling of pride. Madison recounted how it was initially "disheartening to let them down" because she knew they were "very excited about having that feature." Yet, their disappointment quickly resolved as the boys "bounced back incredibly quickly and displayed great enthusiasm," naming her robot "Comfort Kat 4000" since it was a more advanced model than theirs which included the retractable tongue. In the end, Madison felt that not only was she "proud of their accomplishments, but they were proud of mine" and described the interaction as "an extremely heartwarming moment, easily my favorite of the entire experience."

Mastery Experience. Madison developed cognitive content mastery during the training phase when she created successful robots prior to interacting with the fifth graders. Nevertheless, she was still "worried about her ability to understand—let alone teach—coding." Accordingly, she "devoted a lot of time to mastering the coding and concepts" on her own, "working with [her] kit every weekend" until she was "comfortable teaching the codes… and prepared to answer any question." Madison attributed a significant portion of her teaching self-efficacy to this practice, explaining, "had I not invested the time that I did, I would not have felt confident and our team likely would have suffered." The act of teaching the children also enhanced her teaching self-efficacy: "I proved to myself that through determination and practice, I can learn and teach any material that I set my mind to."

The Influence of Madison's Self-Reflection on her Teaching Self-Efficacy

Madison's initial goal for the project was to help her fifth graders have a positive experience: "Above everything, I want the kids to enjoy themselves." She also wanted the children to have "the space to fail and go back to the drawing board" while still finishing the robots in time for the showcase. As the project proceeded, Madison experienced challenges, both in terms of having to carry more of the teaching load than she initially anticipated and in relation to the difficulties of teaching robotics via Zoom. She stated that "the hardest part of this journey was figuring out how to guide my students when I couldn't see what they were doing." She also added that the relationship with the fifth graders was "not as strong as it could be in a face-to-face context" as they tend to be "nervous/shy online." She recounted several strategies she used to overcome these obstacles, including constantly asking Anthony and Henry to hold their work up to the camera and recording videos of her robot to show small parts in explicit detail. Due to these limitations, she transitioned her instructional strategy from inquiry-based to directed: "Initially, I was not planning on having my students copy our robot's code… had we had more time and had we been face-to-face, I would have liked to let my students figure at least half (if not more) of the code out for themselves." She also shared that working with two children instead of one invited inequity and competition, which complicated the teaching task. For example, she explained, children have access to different materials, have different innate talents, and can "feel upset if a group member's robot garners recognition while theirs does not."

Madison met her goals and felt "proud of what [her team] accomplished." As she recounted, everyone "produced a finished product" and "learned valuable lessons about the engineering process." Despite having to exert more control over the fifth graders' building and coding processes than she initially planned, she still gave them the room to make mistakes (e.g., "one of my students built a tail that ended up being too heavy for his position servo to support….

the other realized that his legs were not strong enough to support the weight of his cat's body"), and allowed them "to carry out the process of trial and error and come up with new solutions on their own." She also helped the fifth graders develop resilience as they "learned to take setbacks in stride." She summed up her self-assessment this way: "Overall, I would say that I am pleased with the work that I've done."

With no prior coding, engineering, or teaching experience, Madison didn't feel confident at the beginning of the project. The experience of learning and teaching coding and engineering helped her gain considerable confidence in all three areas. In fact, by the end, Madison suggested that she would not need to complete extensive preparations should she teach similar content again. She explained that she no longer needed the "crutch" of a presentation and was "more than capable of leading a discussion without the help of a slideshow." In her reflection, she states plainly, "I have no doubt that I can incorporate coding in my future classroom."

Madison considered how her instruction could affect her fifth graders' attitudes: "I wanted them to have the best experience possible… their experience with me may shape the way they view the field of engineering." She expressed a commitment to teaching engineering and coding in her future classroom, connecting engineering to her interest in creativity: "creativity is an integral part of engineering." She says the project strengthened her resolve to "nurture not only critical thinkers, but critical makers."

Case 3: Kayla

Kayla is a conscientious and amiable student who identifies as a White female with Hispanic (Mexican) heritage, a mother of two young children, and a lifelong learner. She emphasizes the importance of creating relationships with her students and explained that she likes to "be considerate of everyone." When working in a group, she prefers to take the "backup role."

At the time of the course, Kayla had previous experience working with young children, but the robotics lesson was her first experience teaching elementary-aged students. Before joining the elementary education program, Kayla obtained an associate's degree in social science and certificates in child development and educational support. She also served as an electrician in the U.S. Navy, where she gained some familiarity with engineering. She described her experience in the Navy as providing her the ability to develop and implement electrical design. In her reflection, she described herself as someone who enjoys engineering and coding. Upon graduation, Kayla plans to teach at a lower elementary level, ideally kindergarten.

The Influence of Kayla's Social Interactions on her Teaching Self-Efficacy

Kayla and her engineering partner, Connor (White male), were present and engaged with their cameras on at all sessions. Typically Conner led the instruction to their two fifth graders, Kaleb (Black male) and James (White male), while Kayla closely monitored the boys' engagement and progress. All team members regularly held up components to communicate directions and progress and to give each other feedback.

Kayla and Conner had an easy rapport throughout the Zoom recordings and appeared to enjoy interacting. Kayla described Conner as “a great team member” who “responds [in a] timely [fashion] and [is] involved with the entire learning process.” She went on to say, “he is willing to take extra time to work on the projects assigned” and “when working with the fifth graders…is interactive and encouraging.” She said Conner went “above and beyond” expectations, both in teaching, by taking on a lot of the responsibility, and in the design of his robot, for which he 3D printed parts and enthusiastically shared with the team.

While Kaleb and James (fifth graders) both exhibited enthusiasm for the project initially, James’ competing extra-curricular activities curtailed his attendance and ability to work on and, ultimately, finish his robot. Kayla reported being discouraged by James’ diminishing participation, feeling he “wasn’t as into it” and finding it harder to incentivize him. On the contrary, she appreciated Kaleb’s enthusiasm and reported that her ability to help him complete the robot boosted her confidence and encouraged her.

Kayla was always engaged and prepared for the sessions yet played a predominantly supportive role, especially early on. As Conner led the design process and the instruction related to coding, Kayla held up kit components to illustrate the directions and refocused the boys’ attention as needed. Kayla explained that she made a more significant contribution off-screen, creating slideshows and videos for the children, and attributed her smaller on-screen role to being a less talkative person. Due to the COVID-19 pandemic, Kayla was also responsible for tending to her own young children while she was teaching and occasionally had to mute her microphone or step away to address their needs. Kayla explained that her children regularly asked questions about what she was doing with her robot and how it worked after her Zoom sessions. Adeptly managing interruptions from her children, Kayla maintained focus on the fifth graders throughout the sessions, connecting with them personally, asking about activities in their personal lives, and remembering and revisiting details from one meeting to the next. Kayla’s teaching presence increased over time, especially as the instruction moved from coding to building. In the last Zoom session, Kayla demonstrated how the boys should assemble and program components using her own robot as a model. She also held an individual meeting with Kaleb to help him finish his robot.

Kayla, Conner, and Kaleb’s parrot-inspired robots (see Figure 3) met the requirements of responding with lights, sound, and movement to a user stimulus. Initially, the plan was to let the fifth graders help determine the coding, but this changed: “As time went on, he [Conner - engineering student] kind of just decided it and made a video for us to follow.” The children had more discretion in the build phase, and each robot had a unique look. Conner’s parrot was much more advanced than Kayla’s or Kaleb’s and was recognized in the showcase for its sophisticated design and coding.

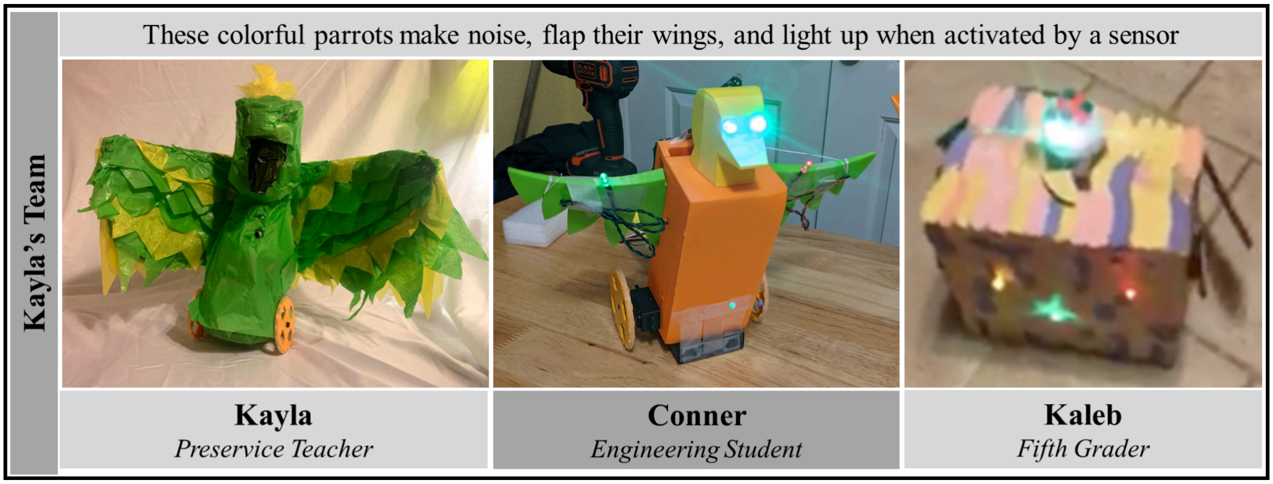

Figure 3. ***Team Kayla's Robots***

Sources of Teaching Self-Efficacy.

Verbal Persuasion. Kayla did not directly discuss any ways in which her engineering partner, Conner, helped to convince her she was capable. However, Conner was very engaged in the project and communicated high expectations for himself and the team. For example, he shared ambitions for his robot during the Zoom sessions: "There's going to be a showcase at the end, and I intend on showing out pretty well…. I'm going to make mine pretty fancy." Conner projected a can-do attitude (e.g., "We got a lot to do for next week, but I think we can do it!") and used inclusive language (e.g., "We'll help you," "We'll show you") that conveyed collective team efficacy, indicating that the team would be able to figure things out and be successful together. While Conner did not use overt statements to persuade Kayla that she could be successful in teaching the children and in making her own robot, his expressed confidence in the team's ability to accomplish its goals may have persuaded her that she could be successful and to invest effort toward that end.

Vicarious Experience. Kayla had the opportunity to watch Conner confidently and effectively instruct the fifth graders. Kayla recognized his ability and compared it to her own, concluding that he may have had "more knowledge on the topic and how to teach it to the students." Kayla's referential comparison [42-43] to a peer she perceived to have superior ability could have discouraged her, but this seems unlikely as her confidence in teaching increased as the sessions progressed. It seems more likely that she benefited from the vicarious experience of watching Conner teach.

Physiological Arousal/Affect. Kayla described both stressful and joyous interactions over the course of the project. While she did not complain about the ongoing challenge of balancing her childcare responsibilities with her teaching obligation, one can assume it added a degree of stress. Kayla's interactions with her children were also joyous, however. As she articulated several times, her son and daughter were very excited about the robots: "from the moment I came and got the kit…they wanted to know what was inside."

Kayla likewise experienced both stress and joy interacting with the fifth graders. In the first session, Kayla reported that both boys "wouldn't keep their cameras on and answer questions, making it difficult to get to know them." While this behavior and James' disengagement caused disappointment, Kayla's later interactions with Conner and Kaleb were consistently positive. For example, at one point in a Zoom session, the team bonded over their interest in NASA:

> Conner*: I had fun. I don't know about you, I had fun. It's pretty cool seeing that actually work. Right?*
> Kaleb*: I'm going to love it no matter what because it is my dream to become a scientist… I want to work at NASA.*
> Conner*: You wanna work at NASA? That's what my shirt is right now [stands up to show his shirt on the camera]. Yep, I'm wearing a NASA shirt.*
> Kaleb*: This is my mouse pad since I'm so into it. [holds NASA mouse map up to the camera]*

Meanwhile, Kayla was laughing, clearly energized by their shared excitement. Conner's enthusiasm added joy to the sessions. In an early session, Conner says, "Our goals for today are to come up with what our animal is going to be. Correct?... All right! That's a big deal, and it's exciting!" Kayla believed that Conner's investment was rooted in his interest in 3D design and printing and that this made the project appealing and fun for him, "which in return was beneficial to the team."

Mastery experience. Kayla gained cognitive content mastery during the training when she successfully built and coded a winch and in the construction of her parrot robot, which she featured prominently in the team's *Shark Tank* pitch, suggesting confidence in its functionality and a level of pride. In terms of teaching, Kayla perceived her lesson with Kaleb to be highly successful and derived confidence from helping him succeed. Kaleb's robot was recognized by Hummingbird™ manufacturer *BirdBrain Technologies* during the showcase. This additional evidence likely validated Kaleb's success and reinforced Kayla's positive assessment of her teaching capabilities. Kayla also introduced her own children to the Hummingbird™ kits, sparking their interest in robotics. She spoke fondly of these interactions and expressed an intention to continue teaching her children about coding. This very informal teaching may have also served as a mastery experience.

The Influence of Kayla's Self-Reflection on her Teaching Self-Efficacy

While Kayla did not spend much time discussing the difficulty of teaching robotics, she explained how it was challenging to teach over Zoom,

> *…due to the computer issues, students being shy, lack of eye contact, lack of ability to assist the students in small tasks such as finding particular items from their robotics kit or pointing to where they should cut out a hole, or even just having all the proper materials ready to go when we get there.*

Despite the adversity of the physical context, Kayla described a supportive social context where she had the assistance she needed from her engineering partner, Conner.

Kayla explained how her goal shifted over time. At first, she was focused on completing the robots, concerned that her grade would depend on their success, but later, she reoriented, and "teaching the kids became the most important thing… figuring out how to work with them." She elaborated: "After meeting with my partner and two fifth graders, I felt like I had an obligation to give them a fun… and proper robotics experience. I tried to put myself in their shoes."

When asked to characterize the success of her lessons, Kayla rated Kaleb (10/10) and James (6/10), separately, given their different engagement levels and the fact that Kaleb produced a successful robot, whereas James did not. This suggests Kayla judged her success as a teacher from her fifth graders' performance. Kayla felt she contributed substantially to the children's success: "I feel like I played a big role. I mean, it seemed like they were like my students."

Kayla offered some critique of her performance, saying, "Maybe I could have taken [on] more teaching aspects," but described the overall workload as "balanced," explaining that she adopted many offline teaching responsibilities. She acknowledged not having as much knowledge as Conner but came to accept that she didn't have to be an expert: "This taught me that it is acceptable to not have all of the knowledge."

Kayla reported gaining confidence in engineering and coding as she went through the project. This was evident in the Zoom sessions. Kayla was almost entirely silent in an early session when Conner was teaching Kaleb how to code various components. However, by the final session, Kayla contributed more actively, making suggestions and pointing out aspects of her own parrot robot to illustrate Conner's instructions.

Despite gaining confidence from the project, Kayla reported still having room to grow. She saw the experience as a first step that helped her understand how to teach engineering and coding at an elementary level. She explained, "I think this *began* my journey of confidence in teaching engineering on an elementary level. The lack of teaching at the level is what I lacked confidence in. This was a great step into a future classroom."

Although her self-efficacy grew, and she called the project a "great experience," Kayla hesitated to describe herself as fully ready to implement engineering and coding in the classroom. Kayla shared that she felt comfortable teaching "*basic* [emphasis added] coding... especially with programs like *MakeCode* that have tutorials that guide you throughout." Meanwhile, Kayla enthusiastically described her own children's excitement for the robots and sought out further coding activities for them. She stated, "I see coding, like everywhere." She went on to say that she likes coding and engineering and plans to integrate both into her future classroom.

Conclusions & Implications

Despite participating in the same project of teaching robotics to fifth graders alongside engineering partners, PSTs Lisa, Madison, and Kayla had very different experiences. These experiences affected the way they felt about the project and the underlying fields of engineering and coding as well as their beliefs about their capabilities in these areas. Differences in their social interactions, including their satisfaction with engineering partners and success interacting with fifth grade students affected the emotions they experienced during the project and the confidence they felt teaching. The functionality of the robots their teams produced also influenced their assessment of their competence. In addition, the ways in which the PSTs perceived the goals of the project and interpreted the project events and lesson outcomes affected the way they framed their performance and assessment of their capabilities. These emotional responses and assessments of their capabilities went on to influence their intentions for teaching engineering and coding in their future classrooms.

Consistent with our prior research showing that a PSTs' satisfaction with their engineering partner correlated with their overall outcomes [10,12], the PSTs' interaction and satisfaction with their engineering partner(s) exerted substantial, although often indirect, influence on the development of their self-efficacy. As was evident previously, PSTs' satisfaction with their engineering partner influenced the role they adopted within their lesson [11]. Their perceived success within that role then affected their self-efficacy. Lisa and Madison were both dissatisfied with their engineering partners and felt compelled to lead the robotics instruction within their teams. They both felt their engineering partners were not sufficiently invested and did not feel adequately supported. Although their interactions with their engineering partners were similar in this regard, and neither likely gained self-efficacy as a result of their direct interaction with their engineering partner, the ultimate, indirect effect on their teaching self-efficacy was different. This was likely due to differences in their interactions with their fifth grade partners. Specifically, Lisa's experience with her fifth graders left her feeling uncertain about her efficacy, especially for coding, while Madison's successful experience with her fifth graders helped her finish the project feeling highly efficacious.

PSTs' social interaction with and perceived success of the fifth graders appeared to wield a powerful influence. This aligns with Bandura's assertion that mastery experiences are the most potent source of self-efficacy. To judge their success, the PSTs were looking primarily toward the reactions of the fifth graders and the products they produced. When they perceived their fifth graders to be engaged and successful, they perceived themselves to be successful teaching. Their interactions with the engineering students may have affected the roles they adopted with the fifth graders, but the fifth graders' responses were the key indicator of their success.

In particular, the fifth graders' affective demeanor during the lessons--and the PSTs' subsequent emotional responses--may have played a significant part in the PSTs' self-efficacy development. As a person driven by social interaction, Lisa was disheartened by her fifth graders' lackluster response to her attempts to bond with them in the first Zoom session. Experiencing these negative emotions may have reduced her teaching self-efficacy and dampened her motivation to invest extra time preparing for the subsequent sessions. In comparison, Madison described the enthusiastic and supportive behavior of her fifth grade partners and feeling moved by their recognition of her successful implementation of the tongue mechanism. Their investment may have helped her feel successful and fuel her motivation to prepare for sessions and counteract the unease she felt collaborating with Drake. Kayla explicitly described how her fifth graders' reactions affected her confidence. She shared how she was distressed by James' disengagement but energized by Kaleb's enthusiasm. Helping him finish his robot led her to rate the success of the lesson as a ten out of ten. It is evident that the PSTs' interaction with their 5th grade partners affected their emotional states during the project, their perceptions of their success, and their teaching self-efficacy.

Although the PSTs seemed to focus most heavily on their fifth graders' responses when evaluating their teaching competence, other sources of self-efficacy were also at play. Unlike Lisa and Madison who did not appear to gain self-efficacy through their interactions with their engineering partners, Kayla seemed to directly benefit from her interactions with her engineering partner, Conner. The vicarious experience of watching Conner's effective instruction may have helped Kayla believe she could also teach robotics effectively. His enthusiasm for the project injected positive energy into the sessions and may have enhanced Kayla's overall affective response. Furthermore, the high expectations he set may have contributed to a sense of collective efficacy. Perhaps most importantly, Conner's engagement in the project and interactions with Kayla and the fifth graders allowed Kayla the time and space to develop her skills and confidence with robotics, thereby enabling her to develop teaching self-efficacy over the course of the project. Connor's expertise and willingness to adopt a leadership role meant Kayla did not have to be the robotics expert at the start of the lessons.

Outside of their team's influence, all three PSTs described the importance of feeling supported by their instructor. The verbal persuasion resulting from this social interaction may have helped sustain their self-efficacy. Madison may have also been motivated by her own tendency to set high expectations for herself. She invested substantial time in teaching herself how to code and in building her robot in order to be prepared to successfully guide her students. Madison credits this investment as a critical reason for her success.

To enhance the potential for teacher preparation to positively influence PST self-efficacy for teaching engineering and coding, the authors suggest teacher educators seek out opportunities for PSTs to teach lessons to students who are likely to respond enthusiastically and achieve success, such as students participating in an afterschool club. Furthermore, they suggest instructors frame success generously, focusing on student engagement in the design process rather than the success of designed products. This should include teaching students to respond to failure with curiosity and tenacity instead of self-criticism. The instructors could have done more to help Lisa perceive her lessons as successful in guiding students through a design process and persevering through failure.

They also support the partnering of PSTs with engineering students but urge collaborating faculty to think carefully about the expectations they set for both parties and the engineering students' incentive to participate in such projects. Kayla believed Conner's enthusiasm originated in his interest in 3D design. Engineering students who are excited about their involvement are more likely to exert positive influences on PST self-efficacy development. Participating faculty should consider the engineering students' learning needs and interests. Furthermore, if there are clear role expectations for the PSTs and engineering students, it may prevent feelings of dissatisfaction. While Lisa and Madison expected their engineering partner to be more invested than they were and take on a larger role in the planning and teaching, their engineering partners may not have shared that same understanding. Faculty must make expectations explicit to ensure both PSTs and engineering students understand their role in the collaboration. Ideally, PSTs' teaching responsibility for the robotics content should increase as their expertise and confidence grows. If engineering students play a larger part in the initial instruction, this can also give PSTs an opportunity to benefit from the vicarious experience of watching the engineering students. Finally teacher educators may want to consider how they match PSTs with collaborating partners and how they require those partners to communicate their expectations. Part of Lisa's frustration with her experience may have related to her desire for a high level of social interaction. Part of Madison's frustration was related to her high levels of conscientiousness and expectations for herself. Although the instructors provided a protocol to establish team goals and norms, more could have been done to select compatible partners with complementary goals and to facilitate this team communication. For example, had Lisa had a more communicative engineering partner, willing to assume a larger teaching role, especially at the start of the lesson, she may have had the time she needed to develop expertise and self-efficacy, and had a more positive experience overall.

This study contributes to the understanding of how social interactions within a robotics teaching opportunity affects PSTs' development of teaching self-efficacy. It provides a window into the complex interactions between teaching partners and between the PSTs and their students to reveal the myriad ways in which those interactions shape the PSTs' beliefs about their capabilities. It especially highlights the powerful influence of student responses on PST self-efficacy and serves as a novel example of an engineering teaching opportunity within teacher preparation. Importantly, it showed that both PSTs and students were able to successfully design, build and code innovative robots by working remotely and to have positive experiences doing so. Perhaps most impressively, it demonstrated that PSTs can persevere and succeed in very challenging teaching situations and can benefit from such opportunities as long as they are adequately supported. Finally, it revealed the interpersonal dynamics within the teams of PSTs and engineering students and can help educators anticipate the challenges multidisciplinary teams may encounter when collaborating.

Limitations

When interpreting the findings and potential contributions of this study, it is important to consider the context in which it occurred. The study was conducted within an NSF-funded project led by instructors experienced in cross-disciplinary collaboration, and teacher educators who were working closely with engineering students and faculty. The project's adaptation for online delivery during the pandemic may have influenced participant motivation in ways unlikely in post-pandemic settings. While the three PSTs reflected typical U.S. elementary PST demographics (gender, race, age, and limited engineering/coding experience), their individual responses may not represent all PSTs. However, similar projects in past semesters yielded comparable outcomes [11,44]. Additionally, the afterschool club setting offered fewer constraints and more individualized teaching opportunities than standard K-6 classrooms, which may affect how PSTs' skills and confidence transfer to larger classroom environments. Consequently, educators and researchers should consider how their unique contexts would shape the outcomes of similar efforts.

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