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COVID-19 as a Magnifying Glass: Exploring the Importance of Relationships as Education Students Learn and Teach Robotics via Zoom

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Keywords

robotics, relationships, self-efficacy, intention to integrate engineering/coding, elementary engineering education, cross-disciplinary

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COVID-19 as a Magnifying Glass: Exploring the Importance of Relationships as Education Students Learn and Teach Robotics via Zoom

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Abstract

Ed+gineering, an NSF-funded program, adapted hands-on robotics instruction for online delivery in response to the COVID-19 pandemic. This qualitative multiple case study shares the experiences of participating education students in spring 2021 as they collaborated virtually with engineering students and fifth graders to engineer bioinspired robots in an afterschool technology club adapted to be virtual. The online context reduced the education students' interactions with people other than the engineering students and fifth graders on their team and thus positioned COVID-19 as a metaphorical magnifying glass amplifying the critical role that these relationships played in influencing the project's outcomes. Through analyzing short-answer reflections, the researchers observed patterns in the ways the education students' interactions with their engineering and fifth-grade partners shaped their teaching self-efficacy and intention to integrate engineering and coding. Education students appeared to gain the most self-efficacy from feeling supported by, but not dependent upon, their engineering partners, and from adopting engineering-teaching roles. Satisfying interactions with fifth graders and successful production of functioning robots appeared to enhance education students' intention to integrate engineering and coding into their future instruction. Education students reported gaining self-efficacy for both engineering and coding during the experience, but were more likely to report feeling confident about teaching engineering than teaching coding at the project's end. Implications and lessons learned are shared, which may be particularly relevant for educators who prepare elementary education students to teach engineering in K-6 settings.

Keywords: robotics, relationships, self-efficacy, intention to integrate engineering/coding, elementary engineering education, cross-disciplinary

Purpose

In March 2020, most schools in the United States closed their buildings and moved instruction online, dramatically decreasing hands-on science, technology, engineering, and mathematics (STEM) learning opportunities for K-12 and university students alike (Gross & Opalka, 2020; National Academies of Sciences, Engineering, and Medicine, 2020; Pew Research Center, 2020; UN, 2020; UNESCO, 2020). Ed+gineering, a National Science Foundation-funded program, adapted hands-on robotics instruction in response to the COVID-19 pandemic in spring 2020 and then again in spring 2021. This paper describes how the intervention evolved across two semesters and shares the experiences of participating elementary teacher education students in spring 2021 as they collaborated virtually with engineering students and fifth graders to engineer bioinspired robots in an afterschool technology club.

Because the circumstances in spring 2021 differed considerably from spring 2020, Ed+gineering's leaders had to develop two different online delivery models. In 2020, participants had been able to interact face-to-face in the first half of the semester before the pandemic forced the project to quickly transition online. In 2021, the project was modified based on lessons learned from 2020; however, conditions were different. The participants did not have the opportunity to build relationships and trust (Crisp & Jarvenpaa, 2013; Jarvenpaa & Leidner, 1999) with their partners face-to-face before collaborating online. Furthermore, the students had experienced a year of COVID-19-impacted learning and may have become fatigued from learning via videoconferencing (Zilka, 2021). This paper considers the ways in which the COVID-19 pandemic influenced the education students' experiences of teaching engineering and coding to elementary students. It also considers how the COVID-19 context illuminated aspects of the project's design. The differing context of the two semesters positioned COVID-19 as a metaphorical magnifying glass amplifying the critical role that relationships played in influencing the project's intended outcomes. This paper discusses the spring 2021 COVID-19-induced adaptation of a robotics activity for online delivery. It explores the ways in which interactions among education students, engineering students, and fifth-grade partners influenced the education students' teaching self-efficacy for engineering and coding as well as their intention to integrate these subjects into their teaching. It discusses benefits and challenges of the adapted model and provides an example of how hands-on engineering instruction can be delivered in a virtual environment.

Background

This study describes an ongoing project in which elementary teacher education students engage in online robotics activities with undergraduate engineering students and fifth graders as part of a larger effort to increase the education students' self-efficacy for teaching engineering and coding and intention to teach these topics. As such, it draws upon literature from a variety of topics, including robotics as an educational approach for learning engineering and coding, online robotics instruction, trust within teams, teaching self-efficacy, and preservice teachers' intention to integrate engineering and coding. These topics are discussed in this section, followed by the research questions that guided the study.

Growing evidence supports robotics as a powerful approach to STEM learning for elementary students (Rogers & Portsmore, 2004) and preservice teachers (Bers & Portsmore, 2005; Jaipal-Jamani & Angeli, 2017; Kidd et al., 2021; Kim et al., 2015; Schina et al., 2021). Robotics merges the engineering design process with computational thinking by engaging students in the construction of three-dimensional artifacts they control via coding. Because robotics involves the manipulation of physical artifacts, it is challenging to implement virtually. Virtual robotics programs do exist, but they mainly engage participants in controlling simulations or teleoperated robots (Holowka, 2020; Witherspoon et al., 2017). Minimal research examines online experiences that engage K-6 or education students in hands-on construction of robots. One existing study investigated an afterschool STEM program that adapted to online instruction during the pandemic by providing individual LEGO Mindstorms kits to students (Obillo, 2021). While students successfully built robots, teachers reported that assisting them via Zoom was challenging as many students chose not to turn on their cameras/microphones. Additional research is needed to determine if hands-on robotics can be effectively taught online, and if education students can benefit from engaging in this practice.

Robotics is a new field for most elementary education students (Jaipal-Jamani & Angeli, 2017; Kim et al., 2015). Learning new skills and attempting a new task (i.e., building a robot) require risk-taking, as there is little assurance that such endeavors will be successful on the first attempt. A supportive environment where collaborating partners trust one another can facilitate such risk-taking and is a predictor of task success (Breuer et al., 2020; Colquitt et al., 2007). To provide a supportive environment for education students, Ed+gineering partnered them with engineering students in an electromechanical systems class. The paired students collaborated virtually during a training/preparation phase in which they learned to build and code robots using Hummingbird Bit® robotics kits and developed lesson plans for teaching robotics to fifth graders. Afterward, they collaborated in the instruction of the fifth graders. Such cross-disciplinary learning draws from social constructivism, which suggests students build knowledge together as they share new perspectives (Vygotsky, 1978). Prior cross-disciplinary research found positive benefits for collaborating education and engineering students who co-taught engineering lessons to elementary students (Bers & Portsmoer, 2005; Fogg-Rogers et al., 2017; Kidd et al., 2021; Pazos et al., 2019, 2020).

Studies suggest face-to-face interactions facilitate development of trust. Individuals engaged in online interactions required additional time to build trust as compared to counterparts interacting in person (Wilson et al., 2006). While prior research on the project suggested that education and engineering students interacting face-to-face were able to form beneficial relationships that helped the education students feel comfortable engaging in robotics activities (Gutierrez et al., 2021), it was unknown whether exclusively online interactions would produce similar results.

Engineering and coding have recently been introduced into state and national standards and are now beginning to be addressed in teacher preparation programs (Rose et al., 2017). However, current elementary education students are unlikely to have the chance to teach these subjects during their professional preparation. Meanwhile, teaching engineering and coding has been found to enhance teaching self-efficacy for those subjects (Fenton & Essler-Petty, 2019; Fogg-Rogers et al., 2017; Kidd et al., 2021; Perkins-Coppola, 2019; Rich et al., 2017), so preservice teachers are likely to benefit from such opportunities. Ed+gineering wanted education students to teach engineering and coding in a low-risk and supportive environment to help build their confidence. The Ed+gineering robotics project was created in 2019 to provide that opportunity. Paired with engineering students who were likely to be more knowledgeable in these subjects and able to provide technical assistance, the education students were given the chance to try out teaching in an afterschool club context where student grades or test performance were not at stake, and they could experiment with new pedagogies and content without worrying about significant negative repercussions should a lesson go awry.

Ed+gineering's robotics project produced successful results when implemented face-to-face, with education students reporting that they derived motivation and benefits from interacting with their fifth-grade partners (Gutierrez et al., 2021). The current study was conducted to see whether similar results could be achieved in a fully online context. Research was needed to understand how interacting with the elementary students exclusively via Zoom would influence the education students' experiences and the overall success of the project. It was hoped that investigating the success of the adapted model could help educators understand the challenges and benefits of teaching robotics online and the viability of the model as a means to enhance education students' teaching self-efficacy and intention to integrate engineering and coding.

Self-efficacy, or "people's beliefs about their capabilities" (Bandura, 1993, p. 118), is developed from social experiences and self-perception, and is influential in determining outcomes. Self-efficacy then is often tied to people's interactions with others and their reflections on those interactions. Bandura (1997) discussed four sources of self-efficacy–mastery experiences, vicarious experiences, social persuasion, and affect–all of which of which can occur in social interactions. Teaching self-efficacy, or the belief in one's capability to execute the necessary actions to successfully complete a specific teaching task (Tschannen-Moran et al., 1998), has been linked to willingness to use technology (Teo, 2009) and improved student achievement (Caprara et al., 2006). Teachers with greater self-efficacy tend to be more willing to experiment and more likely to achieve positive outcomes. As such, considerable attention has been placed on helping preservice education students develop teaching self-efficacy. Recent research has focused on domain-specific teaching self-efficacy (Klassen et al., 2011). This study is concerned with education students' teaching self-efficacy for engineering and coding specifically.

If elementary teachers are to teach engineering and coding, not only do they need confidence and competence in these areas, but they must also see a need, and have a desire to teach these subjects (Rich et al., 2017). In other words, future teachers must develop an intention to integrate coding and engineering into their instruction. As engineering and coding have only recently been added to national and state standards at the K-6 level, there are few studies that explore future elementary teachers' intention to integrate engineering and coding into their future lessons. However, there appears to be a connection between intention to integrate and teaching self-efficacy.

Teaching self-efficacies for engineering and coding have been found to be significant predictors of intention to integrate these subjects (Banas & York, 2014; Joo et al., 2018; Lin & Williams, 2016). It follows that positive experiences teaching robotics that cultivate teaching self-efficacy could also help cultivate education students' intention to integrate engineering and coding, especially if the children are enthusiastic to receive the instruction. The robotics project recruited interested children to participate in an afterschool technology club. The enthusiasm of these children may have helped the education students have successful teaching experiences and thus contributed to their intention to teach these subjects. Previous research on Ed+gineering found that collaboratively teaching engineering positively influenced education students' intention to integrate engineering into their future instruction (Cima et al., 2021) and education students specifically discussed being motivated by their interactions with the children (Gutierrez et al., 2021). This study contributes to emerging research investigating preservice teachers' intention to integrate engineering by exploring the role that education students' interactions with fifth-grade partners had on their intention to integrate coding and engineering, and how an online teaching context influenced this impact.

Research Questions

This study aims to uncover how teaching robotics to fifth graders virtually alongside engineering students in the context of the COVID-19 pandemic affected elementary teacher education students' beliefs about their ability to teach engineering and coding and their interest in doing so. Specifically, the researchers seek to identify patterns in education students' interactions with their engineering student and fifth-grade partners that relate to their teaching self-efficacy and intention to integrate engineering and coding into their future instruction. While it is difficult to draw causal inferences in a qualitative study and to establish linkages between COVID-induced changes in the project model (e.g., teaching online via Zoom) and education students' outcomes, a goal of this study is to identify patterns that can guide further investigation and help other educators structure collaborative robotics experiences to promote positive learning experiences and attitudes.

Previous research on Ed+gineering found that collaboratively teaching engineering in a face-to-face modality positively influenced education students' knowledge, teaching self-efficacy, and intention to integrate engineering (Cima et al., 2021). We wanted to see whether the education students in spring 2021–a fully online implementation–reported similar outcomes, and to what extent they suggested the COVID-19 context influenced their relationships and success in the project. We include a summary of the project's 2020 model and lessons learned from that implementation in order to illuminate how differences in education students' experiences may be related to both instructor-imposed changes and variations in student behaviors associated with the pandemic timeline (e.g., Zoom fatigue). Accordingly, our research questions include:

1. How did elementary education students describe their relationships with their engineering student partners and how did these relationships relate to their self-efficacy for teaching engineering and coding?
2. How did elementary education students' interactions with their fifth-grade student partners, including the functionality achieved with each of their final robots, relate to their teaching self-efficacy and intention to integrate engineering and coding?

Methods

Study Context

The robotics project described in this study was funded through two interrelated National Science Foundation grants aimed at broadening engineering participation and improving elementary education students' competence and confidence for integrating engineering into K-6 classroom instruction. The project partnered two groups of students at Old Dominion University in Norfolk, Virginia to teach engineering lessons to fifth graders as part of their required coursework: elementary teacher education students in an instructional technology course and undergraduate engineering students in an electromechanical systems course. The classes were scheduled concurrently to enable synchronous interaction. The students completed robotics, teamwork, and lesson-planning activities during a cross-class training phase in the first weeks of the semester. This helped to prepare them for the cross-class teaching phase that started midway through the semester.

The teaching phase was designed to be a unique combination of co-learning and co-teaching so the education students could learn while they were teaching the fifth graders. When the partnered education and engineering students first started interacting with their assigned fifth graders, they acted as teachers, passing on their newly acquired knowledge of robotics to the children. As the project progressed, all participants became co-learners, troubleshooting code and tweaking designs to help each other achieve functioning robots. In the end, it was not uncommon for the fifth graders to teach the education students new coding tricks they had acquired. This combination of roles was also intended to help the education students understand that they did not need to be experts in order to introduce engineering or coding into their teaching.

While the goal of the project for the education students was to enhance their confidence and competence with coding and engineering and to provide a hands-on engineering teaching experience, the goal for the engineering students was to enhance their collaboration and communication skills, especially with non-technical audiences. Both groups of students were graded on project activities, such as creating a lesson plan and reflecting on their experience.

Each education student was assigned to work with one or two engineering students to plan and deliver instruction to fifth graders in an afterschool technology club at a local school. The first author recruited students for the club via a Zoom call during the fifth graders' math class. Students interested in technology or robotics were encouraged to join. The club met for 1.5 hours once per week, for five weeks, during the college students' class time. The intention of the club was to provide a low-risk environment in which education students could practice using educational technologies with elementary students and to expose both the education students and the elementary schoolers to engineering and coding via robotics. Furthermore, the robotics activity served as a means for the education students to gain confidence with recently adopted state standards in engineering and coding for which they traditionally receive little preparation (Rose et al., 2017; Trygstad et al., 2013).

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Within the club sessions, each team (i.e., one education student, one or two engineering students, and one or two fifth graders) was tasked with collaboratively designing bioinspired robots using block coding and simple mechanisms. Bioinspiration was selected as a theme due to its ability to stimulate interdisciplinary connections, encouraged in elementary education, and because animals, often the source of biomimicry, appeal to most children. Additionally, one author has significant expertise in bioinspired robotics. Hummingbird Bit® kits were selected because they utilize web-based block coding that is relatively easy for beginners to master and the hardware is designed for children to manipulate, yet they include a variety of components enabling users to scale up complexity as desired. In preparation for the club, the education and engineering students participated in collaborative training sessions where they explored the Hummingbird Bit® kit's hardware and software and planned their lessons for the fifth graders.

The course instructors provided the structure and goals for the lessons while the education and engineering students developed plans for teaching the specific objectives (e.g., introducing the engineering design process). The lessons began by introducing the fifth graders to engineering, bioinspired robotics, and the Hummingbird Bit® kits in the first 1.5-hour session, then moved into the engineering design process over the next three sessions with the challenge of building, coding, and testing a bioinspired robot that incorporated sensing, movement, light, and sound. In the final session, the education and engineering students helped their partner fifth graders create a "Shark-Tank" style pitch for a showcase event during which the fifth graders' families were encouraged to vote for their favorite robots.

COVID-19 Adaptations

When schools closed in March 2020, that semester's club was moved online. Instruction shifted from whole-group face-to-face sessions to individual team-based Zoom meetings and each participant was provided with an individual robotics kit to use at home. These adaptations increased the expectations for the education students. In the face-to-face setting, the education students supported the design of a single team robot. The virtual context eliminated this possibility. Instead, the education students had to work on their own robots while guiding their fifth-grade partners through the design of their own robots. The education students also structured each lesson and hosted their teams' Zoom sessions. The roles of the faculty also changed. They shifted from leading course/club meetings to providing logistical support and technical assistance in individual team Zoom sessions.

In spring 2021, both of the collaborating university courses and all the club sessions were conducted entirely via Zoom. Building on lessons learned in 2020, the instructors introduced changes in the project format. Instead of the team-based Zoom meetings used in spring 2020, spring 2021 participants met in a single whole-class Zoom session and transitioned into breakout rooms to work within their teams. While this afforded the education students less autonomy in structuring their lessons and less time to build robots alongside their teammates, it facilitated technical support from instructors, eased the technical burden on education students, and simplified communication with fifth graders and their parents. Hoping to replicate spring 2020 results showing education students benefited from having a kit at home (Gutierrez et al., 2021), all participants were given a robotics kit which they kept for the duration of the project. The design challenge was modified. Given the global pandemic context, each team was tasked with designing a bioinspired COVID companion robot that could assist or comfort individuals during the pandemic. As was the case in prior iterations, robots were expected to utilize lights, sound, movement (e.g., flapping a wing or wagging a tail), and sensing (e.g., detecting proximity to a hand using a distance sensor) to interact with a human user. However, drawing on findings from spring 2020 suggesting the creation of individual robots had a positive impact on education students (Gutierrez et al., 2021), all spring 2021 participants (fifth-grade students, education students, and engineering students) were *expected* (rather than just *encouraged*) to design their own robots. Furthermore, the engineering students were tasked with developing an advanced model of their team's conceived robot. This change was intended to elicit greater investment and accountability from the engineering students and increase the rigor of their role within the project.

Because all team interactions occurred online, spring 2021 partnerships were strategically formed based on common interests and education students' learning needs. To the extent possible, students were partnered with others with similar hobbies/interests (e.g., gaming, outdoor activities). Education students who expressed high levels of discomfort with engineering subjects were intentionally paired with engineering students who had prior teaching/tutoring experience. The assumptions were that individuals with commonalities would have an easier time establishing a bond online, and that education students who felt less confident would benefit from having a partner who had previous experience providing academic support. Prior research has shown that trust takes longer to establish online, and trust is important in a partnership that requires risk-taking and exposes vulnerability associated with learning new skills (Colquitt et al., 2007; Wilson et al., 2006). It was hoped that intentional partnering could accelerate the development of trust.

In spring 2020, education students sat beside their engineering partners during a training phase when they collaboratively built a single team robot that utilized a sensor to trigger light and movement (see Figure 1). This was not possible in spring

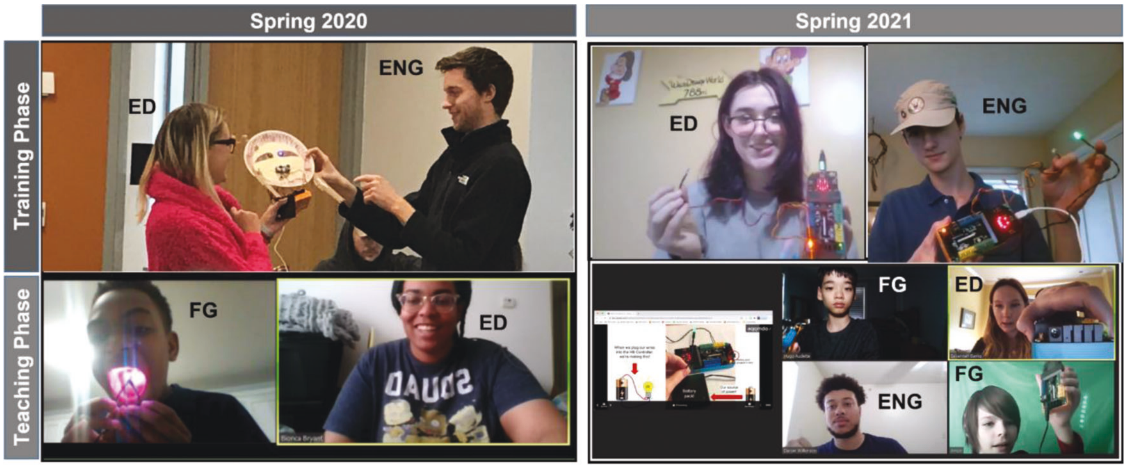

Figure 1. Training and teaching phases for collaborating education, engineering, and fifth-grade students in spring 2020 and spring 2021.
Note. ED = education student; ENG = engineering student; FG = fifth grader. All participants shown in the images provided signed photo release forms, including those of minors.

2021 where education and engineering students completed their training in Zoom breakout rooms, working with individual robotics kits. While partners were tackling the same tasks, the physical separation inhibited their ability to assist one another. The online modality complicated learning associated with physical manipulation of robotic components and prohibited the construction of a shared robot structure. Visible in Figure 1, spring 2021 participants often resorted to holding components up to the camera while exchanging robot hardware construction ideas as they could not physically assist each other.

The teaching phases in both spring 2020 and spring 2021 occurred via Zoom. However, in 2020, not only did the education and engineering students have a chance to work side-by-side prior to the transition, but so did the education students and the fifth graders. There were four in-person technology club sessions (unrelated to the robotics project) prior to the COVID-induced school closures where the fifth graders and the education students created content (e.g., videos) together using technology. Sharing the same physical space may have helped spring 2020 participants develop trust and feel comfortable when they transitioned online and faced the challenging endeavor of designing robots online. In their reflections, spring 2020 education students explained how interacting face-to-face with their engineering and fifth-grade partners prior to moving to remote learning helped them establish bonds that made it easier to collaborate over Zoom later in the semester (Gutierrez et al., 2021). In the teaching phase of spring 2020 shown in Figure 1, a fifth grader is holding a lit LED in his mouth. This playful interaction that occurred over Zoom may have been facilitated by the relationship the participants had established during their face-to-face sessions. In spring 2021, all aspects of the project took place online where it may have taken more time for participants to build trust (Wilson et al., 2006).

Participants

In spring 2021, nine undergraduate elementary teacher education students collaborated alongside eleven undergraduate engineering students and fourteen fifth graders to engineer individual COVID-companion robots. The education students comprise the cases for this study and as such the analysis is focused on their perspectives of the interactions within their team. Seven teams consisted of one education student and one engineering student; however, two teams (Lisa's and Deja's) included two engineering students. Each team had one or two fifth graders. Table 1 lists the demographic information of the participants in each of the project teams, listed by case (see *Data Analysis* section for further detail).

All the education students were new to robotics. One student had electrical engineering experience in the U.S. Navy; all others were new to engineering. Three students had previous exposure to coding. One student had taken a coding class prior to changing her major to education, one had assisted in a kindergarten class learning coding, and another coded a lightboard during theater club. Most of the engineering students had prior coding experience but were new to robotics. About half of them had previously taught or tutored students in some capacity.

Table 1
Spring 2021 team demographics by case.

Education student		Engineering student partner(s)	Fifth-grade partner(s)
Case	Race/gender	Race/gender	Race/gender
Crystal	White female	Black male	Black female
Lisa	White female	Black female and White male	Multiracial female and Black female
Tamaria	Black female	Asian Indian male	Multiracial female
Kayla	White female	White male	White male and Black male
Carmen	Multiracial female	White male	Black female
Olivia	White female	White male	White female and White female
Deja	Black female	Black female and White male	White male
Madison	White female	Black male	White male and Multiracial male
Mirella	White female	Black female	White female and White female

Data Collection

This study focused on the experiences of the nine elementary education students as they taught robotics with their engineering partners during a virtual afterschool club. To understand the education students' experiences, the researchers collected short-answer written reflections at the end of the course, with approximately 30 prompts (see Appendix) targeting various aspects of the project, such as team dynamics, interaction with fifth graders, impact of the virtual setting, access to robotics kits, motivation for and value of the project, self-efficacy, and intention to integrate engineering/coding. Because robotics includes engineering and coding, questions were asked related to education students' attitudes toward each of these topics.

In addition to the reflections, the authors used pictures, videos, and other documents describing the participants' robots to evaluate how well each participating education student and fifth grader met the goal of designing, building, and coding a robot. Robot functionality was included in the analysis because the production of a working robot was understood as a central aim of the club and all participants were focused on this goal. Furthermore, the robots were featured and voted on during a virtual family showcase held via Zoom at the end of club sessions, and as such, there was social pressure to have a good product. Education students reported wanting to help their fifth graders produce a robot of which they were proud, and using the final robots as a means to judge how much their partners learned and as a measure of their own success.

Data Analysis

A multiple case study approach (Yin, 2009) was used for this study. This methodology aligned well with the study's purpose of understanding how each education student's experience of teaching robotics to elementary students alongside their engineering partners related to their teaching self-efficacy and intention to integrate engineering and coding. The researchers were interested in detecting any patterns between the education students' experiences and their attitudes that could guide further investigation and help structure positive collaborative learning experiences. As such, a multiple case study methodology was deemed appropriate (Ridder, 2012).

To gain insight into education students' experiences and to answer the research questions, the authors followed the steps of qualitative content analysis (Rourke & Anderson, 2004). First, the researchers analyzed the nine education students' reflections with *a priori* codes based on the objectives of Ed+gineering's grants (e.g., team interaction, teaching self-efficacy, intention to integrate engineering). Through multiple rounds of coding and discussion, they added and modified codes as new topics emerged (e.g., adopting engineering roles, access to robotics kits). Subcodes (e.g., workload balance, "shy" fifth graders not turning on cameras and microphones, sources of self-efficacy) were also developed during the iterative process of analysis. As a result, a final codebook was established. Using this codebook, three of the authors coded and discussed the nine reflections until full agreement was reached. The three researchers then used specific reflection prompts to generate a summary of each case as explained below.

The authors used a rating scale of low, medium, or high to characterize the education students' satisfaction with their relationships and the extent to which they achieved the project outcomes. The education students' answers to specific reflection prompts were targeted to generate the ratings for the relationships, teaching self-efficacy, and intention to integrate engineering/coding. Pictures, videos, and other documents describing the participants' robots were used to generate the functionality ratings for the robots. Three authors discussed each rating until there was an agreement on characterizing the education students' project experiences summarized in Table 2.

Table 2
Spring 2021 robotics project outcomes organized by case.

Case	Satisfaction with		Robot functionality		Self-efficacy for teaching		Intention to integrate	
	Engineering student(s) Relationship	Fifth grader Interaction	Education student	Fifth grader(s)	Engineering	Coding	Engineering	Coding
Carmen[a]	H	H	H	L	L	M	H	H
Crystal	H	H	H	H	H	H	H	H
Deja	H	H	H	M	H	L	H	H
Kayla[b]	H	M_1	H	M_3	M	M	H	M
Lisa[a]	L	L	L	L	M	L	H	L
Madison	L	H	H	H	H	H	H	H
Mirella[a]	H	M_2	H	H	H	H	H	H
Olivia	H	M_2	H	H	H	L	H	H
Tamaria	H	H	M	M	M	L	M	L

Note. H = high level; M = medium level; L = low level; M_1 = high level of interaction with one fifth grader and low level with the other; M_2 = low level at the start, increased to high by the end; M_3 = one fifth grader built a functional robot and the other did not.
[a]Prior experience with coding. [b]Prior experience with engineering.

There were six reflection prompts that generated responses characterizing the education students' level of satisfaction (i.e., low (L), medium (M), or high (H)) with their relationship with their engineering partner(s). One prompt sometimes contained multiple questions, for example: "*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.*" Education students who described their relationship as "effective," "a good team," or said they were "satisfied" with their collaboration were rated as having a high level of satisfaction. Education students who reported being "unsatisfied" or "not satisfied" were recorded as having a low level of satisfaction. There were no responses that suggested a medium level of satisfaction.

There were seven reflection prompts that were used to characterize education students' satisfaction level with their fifth-grade partner interactions. Education students who reported consistently positive interactivity were characterized as having a high level of satisfaction. Education students who reported being frustrated or challenged by low levels of interactivity with their fifth graders, often characterizing their students as "shy" or unwilling to engage through microphones and cameras, were designated as having a low satisfaction level with their interactions. Education students whose satisfaction changed over the course of the project, often from starting out low and increasing to high, or who had satisfying interactions with only one of their students (five of the nine education students had two fifth-grade partners), were labeled as having a medium satisfaction level.

The education students' answers to prompts related to their confidence with engineering and coding were used to characterize their teaching self-efficacy, such as: "*How confident are you in your ability to teach an engineering [or coding] lesson in your future classroom*?". Responses of "very confident" were interpreted as a high level of teaching self-efficacy, whereas responses that expressed confidence with reservations such as "I could teach a very simple engineering lesson to young students" were coded as medium, and responses that suggested education students wanted more practice before teaching or would prefer to assist with a lesson rather than teach it were coded as low.

The prompt "*How likely are you to integrate engineering [or coding] in your future teaching? Why?*" was used to describe education students' level of intention to integrate engineering [or coding] into their future classroom. If a student responded definitively that they were "very likely" to teach the content, this was labeled as high, whereas a more tentative response, such as "most likely" or "I think I would," were labeled medium, and responses that said they were "less likely" or would "probably not" integrate were labeled as low.

There was high variability in the quality and complexity of the robots produced. As seen in Figure 2, some robots were highly polished demonstrating artistry and durability, while others were less ornate and/or fragile. A few robots incorporated multiple functionalities and elaborate coding (e.g., robot looked very much like the mimicked animal, flapped wings, flashed LEDs, and played a song when triggered by a sound sensor), while others used simple box-type body structures and only basic commands to blink LEDs or turn on/off a continuous servo, without any use of sensor triggers. The former class of robots successfully met the requirements of the assigned design challenge of producing an interactive COVID companion robot, while the latter failed to do so. If a robot was successfully engineered to respond to a stimulus with light and movement and was durably constructed in time for the showcase for fifth graders' families, it was deemed high-functioning (H). Team Parrot and Team Comfort Kat produced robots in this category (see Figure 2). If a robot incorporated only light or movement, and/or did not hold together, and/or was not completed in time for the showcase, it was deemed medium-functioning (M). Team Dinosaur produced robots in this category (see Figure 2). If it incorporated

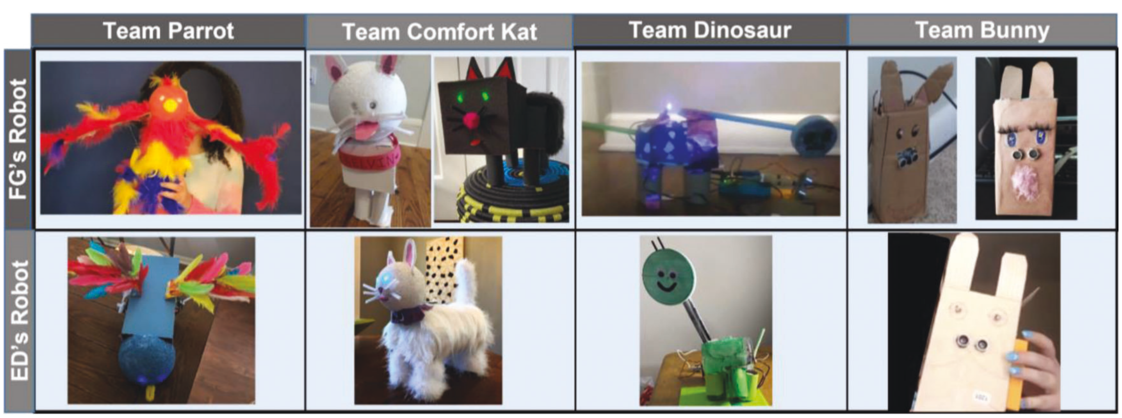

Figure 2. COVID-companion robots made within the teams by education students and fifth graders.
Note. Each team developed its own vision for a COVID-companion robot. The education student and each fifth grader on the team designed their own version of the envisioned robot. ED = education student; FG = fifth grader.

neither light nor movement, and/or was unfinished at the end of the project, it was deemed low-functioning (L). Team Bunny's robots fell in this category (see Figure 2). Five of the nine education students worked with two fifth graders. In four of these cases, both fifth graders produced robots with the same level of functionality. However, in Kayla's team, one fifth grader produced a functional robot whereas the other did not. In this case, the functionality was averaged, and an M (medium) was recorded. Table 2 lists the levels of functionality for the education students' and the fifth graders' robots.

Findings

Connections Between Education Students' Relationships with Their Engineering Student Partner(s) and Their Self-efficacy for Teaching Engineering and Coding (RQ1)

Education students generally characterized their relationships with their engineering partners as positive. Seven of nine students expressed overall satisfaction (see Table 2). Education students often reported feeling supported and drawing motivation from their partners. For example, Deja described being satisfied because her engineering partners "were very understanding and helped a lot with the coding process…where one of us felt uncomfortable or unsure of something we were all able to work together to figure it out." Carmen explained how her relationship with the engineering students (and with her fifth-grade partners) was a source of motivation:

> I had a great relationship with my teammates. I shared a lot in common with my [fifth-grade] student and my engineering partner and I always had something to talk about. This made me even more motivated to do my best.

Two education students, Madison and Lisa, did not consider their teammate relationship positive or effective. As Lisa explained, "I do not think I benefited from working with my engineers. I am unsatisfied with my partner experience due to their lack of commitment, time management, and communication to the project."

The factors which seemed to most heavily influence education students' perceptions of the success of their relationships with their engineering partners included communication and investment toward the project. Education students also discussed the ways in which they moved beyond traditional roles that were in their comfort zones, to teaching engineering content, which was a new and intimidating role for many, and the ways in which their interactions with their engineering partners influenced their learning and confidence during this journey. These topics are discussed below.

Communication Between Education and Engineering Students

Education students considered effective and continuous communication critically important to the project. In previous, face-to-face iterations, it was easy for education and engineering teammates to have side conversations while teaching, or to solicit help from classmates outside their teams. In the Zoom context, this informal communication was more challenging. As Madison explained:

> Collaborating online is entirely different than collaborating in person. Were we in person, [engineering student partner] and I could have stepped away from our students for a few minutes to have conversations about our lessons and interactions in real time; this is very hard to do over Zoom. While you can send private chats over Zoom or text your partner, you risk disrupting the flow of the lesson.

Madison, along with one other education student, Lisa, reported a low level of relationship satisfaction. Both students discussed frustrations from working exclusively in an online environment. Lisa described a negative semester-long experience communicating with her two engineering partners, and attributed at least part of the difficulty to collaborating over Zoom: "It gave them a curtain to hide behind instead of turning on their cameras and contributing to the work." Madison reported a similar sentiment: "When shaking accountability is as easy as closing one's laptop, how indebted does one really feel to a stranger they're working with online?" Madison expressed anxiety about her role, and a persistent "fear of overstepping" which she partly attributed to the medium, adding that "it can be very hard to pick up on others' feelings when we are separated by a digital barrier." Lisa suggested in future courses where online collaboration is unavoidable that "the instructors stress the importance of communication and time management" for both education and engineering students. Crystal, an education student who was satisfied in her relationship with her engineering partner, also emphasized the importance of communication prior to and throughout the project to promote a positive team experience:

> …meeting with my partner individually without the big group or our fifth grader was very beneficial. Building the connection with each other one-on-one is important to establish that level of respect and work ethic. I think I would just suggest that the instructors keep ensuring everyone (education and engineering partners) meet one-on-one a few times before the club starts with the fifth grader. Even when everything goes back to in-person, this planning time is crucial to establish this connection and mutual respect.

Level of Project Investment

Many education students reported that significant investment was required to be successful in the robotics project and described elaborate preparation prior to their sessions with the children. For example, Madison shared, "I worked with my kit *a lot* outside of class. For every training session […] I spent at least two hours practicing the coding on my own. I also spent an entire day (sunrise to well after sunset) coding and building my [practice robot]." Because they were heavily invested, education students were sensitive to the level of investment from their partner engineers. Education students who were dissatisfied in their relationships expressed disparity between their level of investment and their engineering student partners', and frustration because they perceived that they shouldered more than their fair share of the workload. Lisa conveyed annoyance, explaining that if her partners were not "directly told when and where to add work… [they would] not contribute or meet to complete the project." Madison expressed disillusionment as she contemplated the origin of her partner's "apparent lack of interest": "I'm not even sure he knew that his class would be collaborating with the education students at all." She also considered how Zoom fatigue could be affecting participants more broadly:

> …everyone's school has been moved online, so we now associate Zoom meetings with work. Sometimes, even those of us who enjoy school get burnt out. I can't help but wonder to what extent this affected everyone's feelings toward this project.

Education students who were satisfied in their relationships were more likely to report equitable task distribution and a similar level of project investment between teammates. Kayla explained, "I think we made a great team. […] My partner was very involved and eager to do well for this assignment." She attributed her partner's investment to his attraction to the project, "He has interest in building various projects with a 3D printer, so I believe this was a fun project for him which in return was beneficial to the team."

Moving Beyond Traditional Roles to Lead Engineering Activities

Most education students assumed responsibility for lesson structure and student engagement when planning and carrying out their lessons. Kayla, for example, said:

> I took on more of the actual timeline planning of the overall lesson while [engineering student partner] took some individual tasks such as the engineering design process and coding. I was satisfied with this because I wanted to make sure the whole lesson would flow nicely so it was easier to have him integrate a few parts within the slides I already made.

Because such instructional roles are common to elementary school teachers, and familiar to education students, we called them "traditional" roles. Education students often embraced these traditional roles, but they also described moving beyond them, to take on roles that more naturally fell to the engineering students, like leading their fifth grader(s) through the engineering design process or explaining coding and robot assembly techniques. The education students' willingness to adopt engineering teaching roles seemed to relate to their relationship(s) with their engineering partner(s); however, this connection was not straightforward. Of the education students who felt supported by their engineering partner(s), some indicated that they ventured outside of their comfort zone, while others became dependent on their engineering student to provide technical instruction. In another case, an education student who felt unsupported by her engineering partner took the lead teaching engineering and coding content because she was not confident her engineering partner would fulfill this role. Education students' willingness to adopt engineering teaching roles also related to what engineering content they would be teaching. Many education students explained that they were more willing to provide instruction related to building or to the design process, rather than coding. Examples of all three scenarios (education students feeling supported and teaching engineering, education students feeling supported but depending on their teammate to teach engineering, and education students feeling unsupported and therefore feeling obligated to teach engineering) are presented below alongside a discussion of education students' comfort teaching coding. These examples showcase how education students' relationships with their engineering partners affected the teaching roles they adopted in their lessons.

As an example of a student who felt supported, Tamaria described how interaction with her partner helped ease both of them into new roles:

> I feel like we both benefited from the partnership because we pushed each other out of our comfort zones. He got more comfortable with teaching and simplifying information so that people with less experience in engineering could benefit. I learned more about engineering and how to problem solve and co-teach with another person.

In another example of a supported student, Carmen explained how she and her partner shared the responsibility of teaching engineering content: "My engineering partner and I interchanged roles…for each session. We both handled coding, and built our robots in front of our students together." Carmen's experience was not the norm, however. If education students mentioned teaching engineering content, it was generally focused on explaining the engineering design process or connecting and mounting hardware components like LEDs, servo motors, or sensors. Rarely did education students talk about leading the charge of teaching coding to their elementary student(s). Crystal explained, "I felt most confident about the instruction of biomimicry and teaching about the various parts of the kit. I felt a little less confident about the actual coding."

As coding was new to most education students, learning it required a level of vulnerability. Many education students expressed concern about their lack of knowledge and experience in coding at the project beginning. As Mirella plainly stated, "While we were doing our project, I was scared and clueless." Lacking confidence in their ability to code, many education students appeared reluctant to teach coding content to their fifth grader(s). For some education students, their engineering partner played a critical role in supporting them through this discomfort. While teaching coding can involve the emotional risk of failing and feeling inadequate, being in a supportive relationship seemed to ameliorate this risk. Crystal stated that she learned "more in-depth about the coding and was able to rely on [her engineering partner] for questions and support" and that she "felt a lot more comfortable coding when he was there to bounce ideas off of." Mirella said that her partner "always made sure I am doing the coding and not to miss anything" and taught her that it is okay to fail: "She taught me that teaching coding is fun and it is okay to code wrong and start again." She added that "engineering is hard but when you start understanding and having a supportive team you can enjoy and learn better."

The line between support and dependency may have been thin, however. Neither party may have realized what was jeopardized when engineering students "supported" their partners by taking over the coding teaching. For example, Mirella explained how her partner was "very nice and helpful" when she asked "if I am comfortable teaching the LED lights" and then offered to "do the coding because she is more familiar than me." Many education students reported relying heavily on their engineering partners to either teach them how to code or to write codes for their robots. Olivia shared, "My [engineering] partner focused on explaining the coding and engineering portions during the club meetings, as I myself was learning too." Despite this dependence, education students who relied on their engineering partner for technical instruction still gained teaching self-efficacy, particularly for engineering, and somewhat less so for coding. As Olivia explained, "It helped my confidence by having someone more experienced to help offer advice." Notably, Deja explained how the online format helped her maintain some independence. She explained that she learned "all about the coding process and anything technical" from her partner, but that working online was beneficial to her learning because she had to problem-solve on her own rather than relying extensively on her engineering teammate.

Interestingly, in at least one case, an unsupportive relationship appeared to have a beneficial outcome by motivating an education student to teach engineering and coding content and thereby gain confidence. Madison took a dominant role on her team due to an unsatisfactory relationship with her engineering partner. She described initially being "worried about my ability to understand—let alone *teach*—coding." But, after having difficulty contacting her engineering partner and lacking confidence in his ability to contribute to the lesson, she created a highly detailed slideshow showing her fifth-grade partners how to construct and code their robots. She explained, "After training and with some additional practice on my own, I was surprised to find how easy it was to discuss these concepts, so I did the majority of the teaching."

Connections Between Education Students' Interactions with Their Fifth-Grade Student Partner(s) and Their Teaching Self-efficacy and Intention to Integrate Engineering and Coding (RQ2)

As was the case for their relationships with their engineering student partners, education students' relationships with fifth graders influenced their outcomes. Education students reported primarily positive interactions with their fifth graders; however, some teams described prolonged difficulties eliciting engagement from the children (e.g., fifth graders were reluctant to turn on their camera and/or microphone). Some fifth graders were initially "shy" (a term used by education students in their reflections), expressing low levels of interaction (see Table 2), but became more engaged over time, while others remained shy throughout. In spring 2020, Zoom was a novel learning platform for students of all ages and there were few reports of fifth graders turning off their cameras. By spring 2021, however, all the students in this study had experienced a year of emergency remote learning, much of it facilitated through Zoom, and unexpected and unhelpful norms had developed, such as fifth graders turning off cameras and microphones during Zoom sessions. These behaviors often hampered communication within teams and affected the education students' confidence interacting with the children. For example, Lisa stated: "I felt least confident on the communication portion, my student did not want to talk or turn on their cameras." Lisa continued, explaining how she was "surprised that, even after the fourth meeting, the girls were firm on not turning on their cameras regardless of my efforts to make them feel comfortable and help them through the project." She added that her "shy students only came out of their shells towards the end of the project." Kayla, who also had a shy fifth grader, reported a similar experience: "It was difficult for me to engage with the students for more than one reason. The students wouldn't keep their cameras on and answer questions, making it difficult to get to know them at the beginning of the meetings." Neither Kayla nor Lisa indicated a high level of self-efficacy for engineering or coding at the end of the project, and while they both reported a high level of intention to integrate engineering into their future instruction, neither expressed a high level of intention to integrate coding. While they still reported optimistic attitudes, suboptimal interactions with their fifth graders may have dampened their confidence and enthusiasm.

Despite some difficulty promoting active student engagement in the Zoom sessions, education students expressed high levels of motivation and effort to create successful learning experiences for their fifth graders. Madison explained, "I am very fortunate that my students' and my schedule permitted us to meet outside of class because it was extremely important for me to do so. As a teacher, you have an obligation to give 100% to your students. I wanted them to have the best experience possible." Crystal reported, "[my] motivation and energy greatly increased upon meeting [fifth-grade partner] because she was so interested and it made me even more excited to collaborate and create our robot." She explained how she wanted her partner to have a satisfying experience: "I wanted to help her create a final product she was proud of." Tamaria's reflection adds additional insight into the importance of the connection between the education students and fifth graders:

> My motivation was most affected by my fifth-grade partner. I did not want to let her down or let her get behind so I was focused and tried to stay on top of everything for her benefit. My motivation was also impacted by her mood, if she was having fun and engaged then I was as well but the opposite was true as well. If she got frustrated or upset, I could feel myself getting frustrated and discouraged as well.

Education students' interactions with elementary students also helped them negotiate their lack of expertise in coding. Education students indicated that they learned from the process of teaching their fifth grader(s) how to code their robots, and also sometimes learned new codes directly from their fifth-grade partner(s). Deja, who did not have strong knowledge or confidence in coding at the beginning, said that her fifth grader taught her more about coding than she taught him. Crystal appreciated the opportunity of teaching as it allowed her to "solidify the knowledge" by "reteach[ing] it to someone else." As she elaborated, "we were trained on the kits very quickly and in a rather condensed way, and I think being able to reteach that to someone was helpful for me." Similarly, Madison explained that simplifying information for her elementary students allowed her to have a deeper understanding of robotics:

> Because I had to think of different ways to communicate these concepts, I developed a far deeper understanding of them. I think being a novice worked to my advantage, as I needed to find ways to simplify this information not only for my students but for myself.

A few education students explained how teaching a topic on which they had little expertise helped them understand that they do not always have to be the expert in the classroom, especially when it comes to technologies, and that it is acceptable to learn as they go. Tamaria explained, "I learned how to adjust my teaching methods to accept that I may not always be comfortable with what I am supposed to be teaching and how to learn as I am teaching." Mirella added, "I was so scared at the beginning to teach them wrong, then I realized we are all learning new things and we will be fine."

All the education students reported gaining confidence in doing and teaching robotics. For example, Crystal explained, "I gained so much confidence with engineering and coding. While I know there is much more to learn, I feel confident that I have enough basic knowledge to move forward […and teach…] a coding lesson to younger students." Despite this, as shown in Table 2, several education students reported low teaching self-efficacy, especially for coding, and recognized their need for more support and practice teaching robotics in their classroom. With the exception of one student, Carmen, who had prior coding coursework, education students were more likely to express a high level of confidence in engineering than coding. Carmen, however, expressed more confidence in coding, explaining "coding is fun and simple once you get the hang of it," and meanwhile expressed skepticism about her readiness to teach engineering lessons on her own: "I am

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confident that I will be able to assist in teaching an engineering lesson, but I'm not sure I'm ready to teach one on my own yet." Deja represented the majority of the group in articulating more confidence for teaching engineering than for teaching coding as she recognized that "the engineering process can be taught in a variety of ways without the coding." Low confidence in coding did not prevent Deja from moving forward, however, as she stated, "I feel I can be a great assistant and help another teacher until I feel more comfortable."

Similarly, Lisa and Olivia expressed confidence with engineering but not coding. Olivia indicated an intention to integrate both engineering and coding into her future instruction, while Lisa expressed a need for more research and time with coding before teaching it. This distinction is interesting because Olivia described feeling well supported by her engineering partner whereas Lisa reported feeling unsupported "due to my engineers not responding, turning on their cameras, and waiting till the last meeting to help complete the project." Additionally, Olivia and her two fifth graders successfully created functioning robots, while neither Lisa nor her two fifth graders produced functioning robots by the end of the club. While the researchers can only speculate on the influence of the engineering students, the fifth-grade students, and the success of the robots on the education students' attitudes, these relationships may be worthy of further investigation and align with the literature that unsuccessful teaching experiences negatively impact education students' self-efficacy (Brand & Wilkins, 2007). If Lisa had had a better experience with her engineering partners, or more success helping her fifth graders complete their robots, she may have had more positive attitudes. Madison, on the other hand, who was also dissatisfied with her engineering partner, but who invested heavily in the project, and was able to engineer a high-functioning robot and lead her fifth-grade partners to engineer high-functioning robots, finished the course feeling efficacious in both areas and intends to integrate engineering and coding into her future instruction. Madison attributed much of her confidence to having access to a kit at home and her own efforts to learn to code. As she explained, "Had I not had my own kit to practice with, I would not have been comfortable teaching these concepts to my students. I would go so far as to say that 90% of my learning came from exploration and practice on my own time."

Discussion

This study's purpose was to understand how education students' experiences of teaching robotics to elementary students alongside their engineering partners related to their teaching self-efficacy and intention to integrate engineering and coding and to detect any patterns between the education students' experiences and their attitudes. Detected patterns from the findings could help guide further investigation and structure positive collaborative learning experiences. To that end, the authors considered how and why the current spring 2021 findings differed from the spring 2020 findings, how the project activities served as sources of self-efficacy for the education students, and what key factors seemed to play pivotal roles in education students' experiences, thereby affecting their final outcomes. Ties to existing literature are integrated into this discussion.

When COVID-19 forced the Ed+gineering project to shift online, it changed the way participants interacted and experienced the project. Changes varied between the two virtual iterations of the project. In 2020, education students, engineering students, and fifth graders were able to work on some team tasks in person prior to moving online. These face-to-face interactions helped set the stage for the second half of the semester which occurred online. As was found in prior research (Crisp & Jarvenpaa, 2013; Jarvenpaa & Leidner, 1999; Wilson et al., 2006), established relationships and trust may have made it easier for all parties to embrace the daunting challenge of collaborating online to build bioinspired robots. Contrarily, 2021 participants were limited to interacting online and had to cultivate their relationships entirely through digital platforms. Furthermore, they had endured a year of learning online and were interacting in a climate of Zoom fatigue (Zilka, 2021). As was the case in similar projects including children (Obillo, 2021), some of the fifth graders seemed reluctant to interact with their teammates on camera, perhaps apprehensive about the challenge of trying something new or interacting with unfamiliar people. Furthermore, the Zoom-based learning space was highly structured, leaving little opportunity for spontaneous interactions. This was especially true in spring 2021 when teams interacted in breakout rooms within the larger whole-club Zoom sessions as compared to spring 2020 when each team hosted their own Zoom meeting. The Zoom context also greatly inhibited students' ability to interact with people other than their teammates. These conditions, created by the pandemic, intensified the importance of the participants' team relationships in shaping the project outcomes. Thus, COVID-19 served as a metaphorical magnifying glass, amplifying the critical role team relationships played in the project's success.

While other research has found that practical teaching experiences increase teaching self-efficacy for STEM subjects (e.g., Fenton & Essler-Petty, 2019; Fogg-Rogers et al., 2017; Perkins-Coppola, 2019; Rich et al., 2017), this study explored the ways in which education students' relationships with their engineering student and fifth-grade partners mediated the influence of the teaching experience on the education students' self-efficacy for teaching engineering and coding. The project included three activities within the context of a robotics teaching project that were intended to help develop

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education students' teaching self-efficacy (Bandura, 1997): building robots, planning lessons, and teaching lessons. All three activities provided the students with the opportunity to learn from and with their peers. First, the education students engaged in a collaborative training session with their engineering partners where they built robots. This training session was provided as the first activity for enhancing confidence for teaching engineering and coding because the authors believed that education students' enhanced engineering and coding content knowledge would contribute to their engineering teaching self-efficacy as has been true in robotics and other STEM areas (Gray, 2017; Jaipal-Jamani & Angeli, 2017; Kim et al., 2015; Palmer, 2006; Palmer et al., 2015). Next, the education students planned robotics lessons collaboratively with their engineering partners for their fifth-grade partners. Developing lessons has also been found to contribute to preservice teachers' teaching self-efficacy for engineering (Cima et al., 2021; Kim et al., 2015; Perkins-Coppola, 2019). Finally, they taught their robotics lessons collaboratively with their engineering partners to fifth graders. Teaching engineering lessons has been linked to improved teaching self-efficacy for engineering (Cima et al., 2021; Perkins-Coppola, 2019; Rich et al., 2017). These experiences provided the education students the opportunity to develop self-efficacy for teaching robotics through all four of Bandura's named sources: mastery experience (successfully building a functional robot and successfully teaching their fifth-grade partners to build a functional robot), vicarious experience (witnessing their teammates build a functional robot and/or witnessing their engineering partner successfully teach a fifth grader), social persuasion (affirmation from their partners about their ability to do or explain robotics), and positive affect (enjoyment from working with their partners while engaging in robotics).

The authors drew upon the findings to identify specific interactions and outcomes that were associated with the education students' self-efficacy and intention to integrate engineering. Common patterns and key factors were recognized within those patterns. As seen in Table 2, education students who had low or medium levels of self-efficacy or intention to integrate engineering often had low or medium levels of satisfaction with either an engineering or fifth-grade partner, or their fifth grader partner(s) produced a robot with low or medium functionality. In other words, the education students' satisfaction and roles within their teams, along with the relative success they experienced with their fifth graders, appeared to play a role in shaping the education students' attitudes. The authors mapped the observed patterns (see Figures 3 and 4) to illustrate how these key factors appeared to act as junctions directing the education students toward specific outcomes. For example, the authors observed that when education students reported taking the lead when teaching engineering content, they were usually more likely to express high self-efficacy for teaching engineering, whereas if they reported relying on their engineering partner to teach the engineering content in the lesson, they were less likely to report high teaching self-efficacy. In this way, the authors concluded that an education student's role in their lesson was a key factor channeling them toward, or away from, a desired outcome. These patterns in the reflection data which are elaborated below are speculative as qualitative data inhibit the ability to make causal inferences; however, they have proven useful in directing the authors' research on sources of teaching self-efficacy and intention to integrate engineering, and they may offer insight to educators designing engineering instruction for education students.

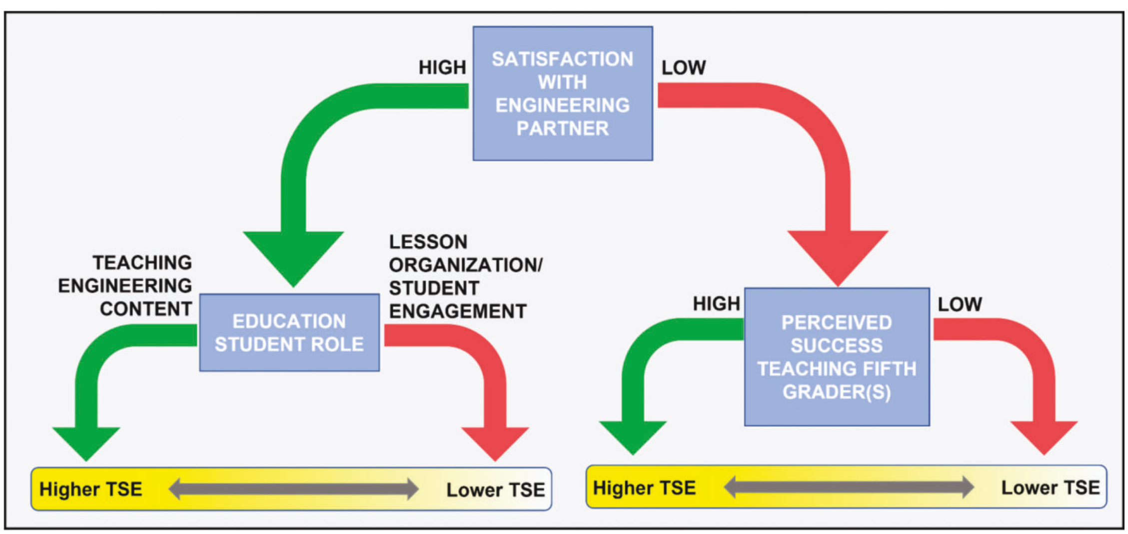

Figure 3. Observed patterns in the connections between education students' relationship with their engineering partners and their self-efficacy to teach engineering/coding.
Note. TSE = teaching self-efficacy.

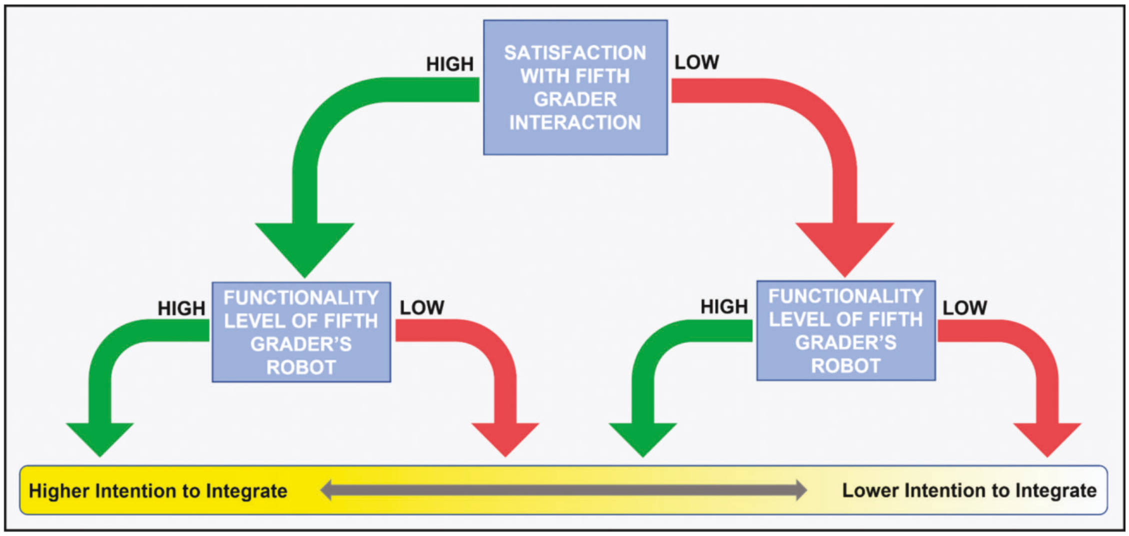

Figure 4. Observed patterns in the connection between education students' interaction with elementary students and their intention to integrate engineering/coding in future classrooms.

One concern the researchers have about partnering education students and engineering students is the potential for education students to become dependent on their engineering peers. As seen in the data, many education students were hesitant to embrace a role outside of their comfort zone and teach engineering content, particularly coding. This was also true in the project's previous iterations when education students were unlikely to report feeling comfortable taking the lead, or even facilitating, teaching coding (Gutierrez et al., 2021). Ironically, over the history of the project, this has at times been less of a concern when education students had problematic relationships with engineering students, and the situation required them to take on larger roles teaching engineering content. When education students have felt well supported, they have often deferred to their partners to explain less familiar engineering content and focused instead on organizational or engagement aspects of the lessons. To maximize their teaching self-efficacy, education students in well-supported contexts must deliberately move beyond their comfort zones and teach engineering concepts. This act requires trust for education students concerned about providing incorrect or incomplete explanations, especially in front of a more knowledgeable peer (Breuer et al., 2020; Colquitt et al., 2007).

If education students are unwilling to take the risk of leading engineering instruction, they cannot gain the benefit that comes with successfully teaching, what Bandura would call a mastery experience, and which has been linked to self-efficacy (Bandura, 1997). Education students may still gain teaching self-efficacy through the vicarious experience of watching their partner teach the content, but this is thought to be less powerful than a mastery teaching experience (Bandura, 1997). In the case of education students who are unsatisfied with their engineering partners, which the findings suggest often results from perceptions of uneven workload or investment, they may be forced to explain the coding and engineering content themselves. If education students teach this content, and believe their efforts are successful, this can serve as a mastery experience and help increase education students' teaching self-efficacy (Bandura, 1997). If, however, education students perceive their efforts to be unsuccessful, this can undermine their sense of teaching self-efficacy. Figure 3 illustrates the patterns observed in the data, showing multiple ways in which education students' relationships with engineering student partners are associated with their teaching self-efficacy.

The cases of Crystal, Olivia, Lisa, and Madison (see Table 2) illustrate the four patterns depicted in Figure 3 between the education students' relationships with their engineering partners and their teaching self-efficacy. Crystal described a high level of satisfaction with her engineering partner and also reported taking an active role in teaching engineering content. She reported a high level of teaching self-efficacy for engineering and coding. Olivia also reported a high level of satisfaction with her engineering partner, but adopted a passive role in the lesson, allowing her partner to teach the engineering and coding content. While Olivia reported a high level of efficacy for teaching engineering, she reported low self-efficacy for teaching coding. Madison reported being unsatisfied with her engineering partner, but produced high-functioning robots with her fifth graders and described feeling successful with her lessons. She reported a high level of teaching self-efficacy for engineering and coding. On the other hand, Lisa, who also expressed a low level of satisfaction with her engineering partners, but did not report as much success with her fifth graders and was unable to help them produce functioning robots, reported a medium level of teaching self-efficacy for engineering and a low level of teaching self-efficacy for coding. Of the four students, none had any prior experience with engineering and only Lisa had prior experience with coding via a lightboard in theater class. While many factors may contribute to teaching self-efficacy, including education students' prior experiences and dispositions, the observed patterns suggest team interactions helped shape the education students' beliefs about their teaching capabilities.

The patterns represented in the bottom half of Figure 3 resonate with current literature showing that experience teaching engineering (Cima et al., 2021; Perkins-Coppola, 2019; Rich et al., 2017) and perceptions of student success (Tschannen & Hoy, 2007) are associated with gains in teaching self-efficacy. Satisfaction with a teaching partner is not a factor commonly studied in conjunction with teaching self-efficacy, as teaching tends to be carried out independently (Tschannen & Hoy, 2007); however, interaction with a co-teacher relates to other sources of self-efficacy, including vicarious experience, social persuasion, and positive affect (Bandura 1997), and our prior work has shown that students' interaction and satisfaction with their teammates relate to the roles they adopt in their lessons (Gutierrez et al., 2023) as well as their level of investment (Gutierrez et al., 2022) and overall satisfaction with the project (Pazos et al., 2019).

Education students' interactions with their fifth-grade partners also profoundly influenced their experiences. A pattern connecting education students' perceptions of their success teaching the fifth graders and their teaching self-efficacy was described above. A related pattern was also observed between education students' interactions with fifth graders and their intention to integrate engineering into their instruction. Education students who were less satisfied with their interactions with one or more of their fifth-grade partners reported a lower intention to integrate engineering than their more satisfied peers. Our findings suggest that education students are motivated to provide satisfying and successful experiences for the fifth graders, and derive motivation based on their perceptions of children's engagement with the project. This was also observed in previous interactions of the project. A case study of one education student from the 2020 iteration revealed that her commitment to, and strong connection with, her fifth-grade partner motivated her to learn engineering and coding (Kidd et al., 2021). This is similar to the work by Skinner and Belmont (1993) who found that "teachers' perceptions of student engagement were especially important as predictors of changes in teachers' subsequent treatment of students" (p. 580). Accordingly, education students may choose whether or not to lead hands-on engineering activities in their future classrooms based on their perceptions of student engagement in such activities during their field experiences in teacher preparation. In our findings, when education students perceived positive interactions and responses from their fifth graders, they tended to express more enthusiastic attitudes toward the project and higher levels of intention to integrate engineering, similar to how "teachers tend to magnify children's initial levels of engagement" (Skinner & Belmont, 1993, p. 580). This seemed to be true of most of the education students, even in cases where their fifth graders' robots failed to meet all required criteria. In all but one case, if education students reported high satisfaction with their fifth grader interaction, they also reported high intention to integrate engineering and coding. Education students may have put more stock in the enthusiasm expressed by their fifth-grade partners in evaluating the project's success than in the physical robots the fifth graders produced. Several studies have found links between student engagement and teachers' motivation to adopt innovative pedagogies (Kim & Jang, 2020; Kim & Kim, 2017). Interestingly, one study revealed that while preservice teachers' perceptions of student achievement were associated with teaching self-efficacy, objective measures of student achievement were not (Jamil et al., 2012). Education students may have prioritized their perceptions of student engagement over other evidence of student success, and/or viewed student engagement as the most important factor by which they measured their own success. Given that the project occurred in an afterschool club, rather than during the school day when grades would be at stake, the education students' focus on engagement and enjoyment would make sense.

In order to judge engagement, the education students may have looked to nonverbal indicators such as children's facial expressions and voice intonations (Altun, 2019); however, when the fifth graders did not turn on their cameras or microphones, it may have been difficult for education students to determine the level of their enthusiasm. Deci and Ryan (1985) have observed the effect of passive student engagement on teachers' behaviors, including causing the teacher to feel incompetent or unliked, and subsequently, decreasing the teacher's motivation. Similarly, over three years of implementation, the researchers have come to appreciate the power of fifth graders' reactions on education students' attitudes. When education students have observed children's excitement for engineering, they have expressed eagerness to teach engineering in their future classrooms. In face-to-face implementations of the robotics project, education students were able to look for signs of enthusiasm across the faces of all the fifth graders in the club simply by looking around the classroom. In COVID-19-influenced semesters, particularly when fifth graders kept their cameras off, education students were less able to make these same assessments. As such, the emotional engagement of their one or two fifth-grade partners became especially critical—another example of COVID-19 acting as a magnifying glass. Figure 4 illustrates the patterns between the education students' interactions with their fifth-grade partners and the functionality of the fifth graders' robots with their intention to integrate engineering/coding into their future instruction.

The cases of Lisa, Olivia, Mirella, Kayla, Carmen, Crystal, Deja, and Madison (see Table 2) illustrate the patterns depicted in Figure 4 between education students' satisfaction in their interaction with their fifth-grade partners and their intention to integrate engineering. Lisa had a low level of satisfaction with her fifth-grade partners on account of their reluctance to turn on their cameras and microphones, and was part of a team that produced low-functioning robots. She expressed a low level of intention to integrate coding. On the other hand, Olivia and Mirella reported difficulty engaging with their fifth graders in the beginning of the project, but expressed higher levels of intention to integrate coding. These two education students' integration intentions may have been higher because their fifth graders' engagement increased over the course of the semester and they were able to create functional robots. Kayla experienced challenges with one of her fifth grader partners, but was satisfied with her interaction with the other. Correspondingly, one of her fifth graders produced a high-functioning robot, whereas the other fifth grader's robot was incomplete and rated low functioning. This may have contributed to her mix of high and medium levels of intention to integrate engineering and coding respectively. Carmen, Crystal, Deja, and Madison all demonstrated high satisfaction in their fifth-grade partner interactions and all reported high levels of intentions to integrate both coding and engineering. The patterns represented in Figure 4 relate to existing literature in that teachers are more likely to adopt new pedagogies, such as teaching with technology, when they perceive student engagement and student success (Kim & Jang, 2020; Kim & Kim, 2017).

Implications and Future Research

The authors plan to explore the presented patterns in future research. They plan to utilize video recordings of online club sessions and education student interviews to further analyze team member interactions and the extent to which education students engaged in engineering teaching roles. They also plan to see if similar patterns emerge in a face-to-face implementation. The patterns may not be apparent outside of the online (i.e., Zoom) context; team-based relationships may lose their potency because education students will be able to easily seek assistance from engineering students outside their teams and observe engagement levels across all participating fifth-grade students. Observing and interacting with other engineering students and fifth graders who have differing levels of project engagement from their teammates could influence their attitudes and motivation. Or, the patterns could be present in face-to-face contexts as well. The generalizability of this current study is limited by its unique context of occurring during the COVID-19 pandemic within a project that was adapted for online implementation and by its atypical partnership between education students, engineering students, and fifth graders with varying requirements for participation. While the project activities were compulsory for the university students as part of their graded course assignments, fifth graders were not required to participate in the afterschool club and did so on a voluntary basis. Also, the afterschool club context provided an informal STEM setting that allowed for flexibility in the content that was covered; topics were not bound by state or nationally mandated standards. It is further limited by its small sample of nine education students and case-study approach based primarily on written reflections. Nevertheless, the implications may be useful to elementary teacher preparation programs, as this population, like our sample, tends to be predominantly female (National Center for Education Statistics, 2021) and to have little to no exposure to engineering or coding (Hammack, 2016). Additional research is needed to understand the importance of education students' relationships with teaching and learning partners in the context of engineering lessons more broadly.

While further research is required, patterns were found between the education students' relationships with their teammates and their attitudes. These patterns will inform the future development of Ed+gineering and may offer insight for other engineering education efforts. For example, given the seemingly critical role of the relationships between education students and engineering students in this study, instructors can create strategies for purposefully pairing students, perhaps including variables such as education students' comfort with engineering and engineering students' prior teaching/tutoring experience or willingness to provide this kind of support, potentially facilitated by teaming software like CATME (CATME, n.d.). Seven of nine education students were highly satisfied with their partners selected via this strategy. Instructors can require education students to adopt engineering teaching roles, like explaining coding and hardware, and they can communicate to engineering students the importance of allowing education students to fulfill these roles, even if it means the education students' directions are not as complete or correct as those an engineering student might provide. Such actions could reduce the temptation for education students to become dependent on their engineering partners. Educators can also design structured training sessions with trust exercises for partners and they can explain the essentiality of establishing trust and regular communication habits when collaborating in novel and challenging engineering tasks. Finally, engineering student roles can be structured to draw upon students' curricular and future career needs and personal interests to promote project investment.

The authors plan to continue researching the relationship between education students and fifth graders. Children's enthusiasm can be infectious and inspire education students to tackle topics and take risks in subjects that have historically been intimidating for them (Watters & Ginns, 2000). If education students' intention to integrate engineering can be swayed by children's excitement (or lack thereof) during field experiences, educators could positively influence education students' interest in teaching engineering by soliciting children who already have an interest in the field. In this project, fifth graders who expressed interest in technology and robotics were invited to participate in the afterschool club. This likely increased the odds that the children would respond enthusiastically to the robotics activities and this enthusiasm may have increased the education students' interest in teaching similar lessons in their own future classrooms. Furthermore, the education students interacted with the fifth graders over several weeks and reported a sense of commitment to the children's success which may have helped them persevere through the challenge of teaching robotics online. Whereas teaching one-off engineering lessons will likely produce positive benefits for education students, longer, multi-session lessons enable the development of a relationship which can motivate education students to tackle tasks they may find daunting, like learning coding. Extended interaction could also allow education students to consider and incorporate their elementary students' backgrounds and interests when planning engineering lessons. Participating in lessons specifically designed to appeal to their interests could help attract young girls and other underrepresented minority students into engineering (Brown, 2017; Letourneau et al., 2022).

Ed+gineering's online implementation of robotics instruction over two COVID-19-impacted semesters acted like a magnifying glass, amplifying the importance of interpersonal relationships within the learning environment and illuminating the ways in which education students successfully engaged in engineering learning and teaching online, even within a hands-on field like robotics. Education students were largely successful teaching fifth graders to design robots over Zoom, especially when they had positive relationships with their teammates. The Zoom context magnified the importance of team relationships and drew attention to ways in which interpersonal interactions related to the education students' teaching self-efficacy and intention to integrate engineering and coding.

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Appendix

Reflection Prompts

SECTION 1: COLLABORATION WITH AN ENGINEERING/EDUCATION PARTNER

1. Did you and your engineering/education partner(s) take on different roles in planning and delivering instruction related to the robotics project? How was this decided? Were you satisfied with the roles you and your partner(s) played? Why?
2. What did you learn from your engineering/education partner(s)?
3. 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.
4. Which collaboration activities (e.g., working with your engineering/education partner(s) in class to learn how to use the components of the Hummingbird kit and to code, communicating with your partner(s) outside of class, working with your partner(s) to help a fifth grader build a robot) did you find most/least helpful? Why?
5. If you were to work on a multidisciplinary partnership like this again, what would you do to ensure a successful collaboration? Or, what would you suggest the instructors should do to help ensure success?
6. How did interacting exclusively online affect your interactions with your engineering/education partner(s)? Consider this in terms of both preparing for your lesson and actually delivering it.

SECTION 2: INTERACTING WITH 5th GRADERS

1. What surprised you about working with your 5th grade partner(s)?
2. What were you trying to teach your 5th grader partner(s)?
3. Did your Zoom lessons go as planned? Did you have to do something different, or in addition to, what you had previously planned? Please explain your answer.
4. Did you attend the March 31st (reading day) session and/or meet with your 5th grader outside of our regular class time? If so, what motivated you to do so, knowing you would not be graded on the success of your 5th grade partner?
5. What do you believe your 5th grader partner(s) learned from the robotics lesson/project? What evidence leads you to believe this?
6. How did working with the 5th graders on coding and engineering affect your understanding of coding and engineering?
7. Who do you think learned more about coding or engineering: you or your partner 5th grader? Why do you think so?

SECTION 4: IMPACT OF THE VIRTUAL SETTING

1. What do you see as the pros and cons of teaching the robotics lessons via Zoom?
2. Collaborating via Zoom to build robots forced everyone on the team to work on their robot alone. In prior WoW Club sessions, teams worked together to build a single robot. What benefits and challenges did you see from each team member designing their own robot?
3. In prior WoW Club sessions, teams shared a single kit that remained at school. Education and engineering students shared one kit to build a robot together during the training phase, then education, engineering and fifth graders shared a kit to build a robot together during the WoW Club sessions. What impact did having your own robotics kit at home have on your learning? In your response, please also explain how often you used the robotics kit outside of class time.
4. How do you believe your experience teaching and learning through Zoom affected your preparation for your future career?
5. How do you think what you learned this semester compares to what you would have learned if all activities were in person?

SECTION 5: LESSON/PROJECT REFLECTION OVERALL

1. What aspects of the lesson/project did you feel most confident about?
2. What aspects of the lesson/project did you feel least confident about?
3. What factors affected your motivation for this project over the course of the semester? For example, did your instructor impact your motivation, the topic itself, your relationship with your teammates, your interactions with the

kids, the feedback you received, outside demands, etc. Please consider factors that positively affected your motivation as well as factors that negatively affected it, and consider how your motivation may have changed over time.

4. How valuable was this project overall? Do you have any suggestions for improving the project in the future? If so, please share your thoughts.
5. If you had to sum up your experience with this project in a single word, what word would that be?

SECTION 6: ATTITUDES ABOUT ENGINEERING AND FUTURE TEACHING

1. What did you learn from this lesson/project that you could apply to your own future teaching?
2. How did your participation in this project affect your attitude toward engineering and coding?
3. How did your participation in this project affect your confidence with engineering and coding?
4. How confident are you in your ability to teach an engineering lesson in your future classroom? What specific factors have impacted your confidence?
5. How confident are you in your ability to teach a coding lesson in your future classroom? What specific factors have impacted your confidence?
6. How likely are you to integrate engineering in your future teaching? Why?
7. How likely are you to integrate coding in your future teaching? Why?

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