Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-023-02383-6 OPEN

Preparing undergraduates for the post-pandemic workplace: Teams of education and engineering students teach engineering virtually

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When schools and universities across the world transitioned online due to the COVID-19 pandemic, Ed+gineering, a National Science Foundation (NSF) project that partners engineering and education undergraduates to design and deliver engineering lessons to elementary students, also had to shift its hands-on lessons to a virtual format. Through the lens of social cognitive theory (SCT), this study investigates engineering and education students' experiences during the shift to online instruction to understand how they perceived its influence on their learning. As a result of modifying their lessons for online delivery, students reported learning professional skills, including skills for teaching online and educational technology skills, as well as Science, Technology, Engineering, and Mathematics (STEM) content. Some also lamented missed learning opportunities, like practice presenting face-to-face. Students' affective responses were often associated with preparing and delivering their lessons. SCT sheds light on how the mid-semester change in their environment, caused by the shift in designing and teaching from face-to-face to online, affected the undergraduate engineering and education students' personal experiences and affect. Overall, the transition to fully online was effective for students' perceived learning and teaching of engineering. Though students experienced many challenges developing multimedia content for delivering hands-on lessons online, they reported learning new skills and knowledge and expressed positive affective responses. From the gains reported by undergraduates, we believe that this cross-disciplinary virtual team assignment was a successful strategy for helping undergraduates build competencies in virtual skills. We posit that similar assignment structures and opportunities post-pandemic will also continue to prepare future students for the post-pandemic workplace.

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Introduction

The COVID-19 pandemic forged a new educational landscape where more students and educators learn and teach online (Kolm et al., 2022; National Center for Education Statistics, 2022; Ndubuisi et al., 2022; Vielma and Brey, 2021). The professional landscape was altered in much the same way (Caringal-Go et al., 2022; Carroll and Conboy, 2020). Many of the people who began working remotely during the pandemic did not return to their workplaces, rather, continued working in remote locations (Parker et al., 2022). This sustained interest in online learning and working illuminated the need for high-quality virtual learning experiences, especially in programs once considered too difficult to implement online, like engineering (Asgari et al., 2021; Bourne et al., 2005) and education (Barnes et al., 2020; Kidd et al., 2023; Rice and Deschaine, 2021), as well as the need for professionals to be able to collaborate and communicate effectively in virtual settings (Carroll and Conboy, 2020).

Ed+gineering is a National Science Foundation (NSF)-funded project that partners engineering and education undergraduate students to design and deliver engineering lessons to elementary students (Gutierrez et al., 2022; Kidd et al., 2023). When the pandemic forced educational institutions around the world to pivot to online learning, we decided to persevere with our project activities, but to change the students' assignments from planning and teaching a face-to-face lesson to elementary school students to developing and delivering an online lesson for the children (Gutierrez et al., 2022). The college students had to collaborate virtually with their teammates to meet the expectations of the new lesson format. Furthermore, they had to learn to use new technologies to collaborate and to create engaging content for the children. We believe our students' learning experiences in the first few months of the pandemic have implications for their preparation for the post-pandemic workplace (Beardsley et al., 2021; Vergara-Rodríguez et al., 2022), and for meaningful online instruction more broadly (Rice and Deschaine, 2021; Zhao and Watterston, 2021). This paper explores the engineering and education students' experiences as they collaborated to meet the new engineering lesson expectations, and it relates these experiences to new skills required for emerging professionals. We begin by discussing the shift toward virtual work environments for engineers and educators post-pandemic and the increased expectations of technology prowess in industry and the classroom. Next, we present relevant literature on social cognitive theory (SCT) and explain how we use it as the theoretical lens for this study. We explain the Ed+gineering project as the context of our study, and finally, we share our findings and discussion.

Since the lockdown in Spring 2020, working remotely has become a viable option for many people. Workers have suggested both positive and adverse effects from working online, but concur that remote working has become a fundamental aspect of the shifting nature of the workplace (Caringal-Go et al., 2022; Carroll and Conboy, 2020). Given engineering's collaborative nature, professional engineers who work remotely need effective ways to collaborate virtually. Accordingly, online collaboration skills have gained greater attention in the field of engineering education (Kolm et al., 2022; Ndubuisi et al., 2022; Vielma and Brey, 2021). Vielma and Brey (2021) found that participating in group projects in a virtual setting was one of the big challenges that engineering students experienced during the pandemic. They suggested that faculty should empower engineering students with best practices for remote collaboration (e.g., collaboratively creating artifacts on shared platforms, reflecting on team members' contributions). Ndubuisi et al. (2022) provided engineering students with global competency training modules that replicated a real work environment to develop their skills for virtual collaboration. Such practices established during the pandemic are likely to be beneficial beyond it as they prepare students for an increasingly global engineering field that requires collaboration across time and place. Furthermore, effective online experiences that allow students to collaborate virtually may help meet a growing demand for high-quality online programs.

While the number of students taking online classes skyrocketed during the pandemic (National Center for Education Statistics, 2022), student enrollment in online courses has been growing for decades (Snyder et al., 2018), and post-secondary online degrees are now offered in programs that have traditionally required students to meet face-to-face in order to complete hands-on activities (e.g., engineering, sciences, education) (Chirikov et al., 2020). Many faculty reported returning to face-to-face instruction in Spring 2022, but, as of Fall 2022, the numbers of faculty teaching exclusively face-to-face are far below the pre-pandemic percentages; meanwhile, more faculty report that they are continuing to teach blended and online courses (Seaman and Seaman, 2022). Students in hands-on and collaborative fields like engineering and teaching need opportunities to interact with people and physical materials during their professional preparation and this is not always easy in an online environment (Bourne et al., 2005). Asgari et al. (2021) surveyed engineering students and faculty during the pandemic, naming the lack of student interaction and peer support as one of the biggest challenges for engineering students. Peer interaction not only provides opportunities for students to develop teamwork skills but can also help provide emotional support and a sense of community, especially for students from underrepresented groups (Williams et al., 2017). Teacher educators likewise struggled to meet the needs of education students in online courses during the pandemic, especially securing field placements where education students spend time in K-12 classrooms. However, some teacher educators exercised creativity in finding teaching experiences for students during the pandemic and found value in online settings (Barnes et al., 2020; Kidd et al., 2023). Some of the faculty in the Barnes et al. (2020) study were considering piloting virtual student teaching opportunities in future courses offered. Given the heightened interest in online programs, this seems wise. Engineering and education faculty need to know how to create meaningful virtual experiences for students in online courses and to prepare their students for virtual work environments that may include collaborating and teaching online.

The growth in online education is not limited to higher education; the number of K-12 students enrolled in online courses has been gradually increasing for years (Barbour, 2017). While teacher educators recognized the need for preservice teachers to learn online pedagogy and educational technologies before the pandemic (Archambault et al., 2016; Office of Educational Technology, 2017), the pandemic punctuated this message, demonstrating that teachers must be prepared to rapidly transition to online teaching at any point (Rice and Deschaine, 2021). Zhao and Watterston (2021) pointed out that the pandemic ultimately changed the most important unwritten school rule —"all students must be in one location for education to take place" (p. 8). In response to this change, they suggest that instructional delivery should capitalize on "the strengths of both synchronous and asynchronous learning" (p. 3). Being able to teach effectively online, utilizing both synchronous and asynchronous pedagogies, requires competence in educational technology and an understanding of how to use technology to teach specific content areas (Koehler and Mishra, 2009).

The sweeping transition to remote learning and working during the COVID-19 pandemic led to the intensive use and reliance on information and communication technology (Chan et al., 2022; DeFilippis et al., 2020; Smith et al., 2021; Ziemba and

Eisenbardt, 2022). As a result, the importance of preparing technology-proficient college graduates has increased. Kolm et al. (2022) found that competency in information and communications technologies was critical for the success of college graduates and essential for international and online collaboration. Hadgraft and Kolmos (2020) assert that engineering students need to learn technologies because they will need to be able to understand the needs for future technologies and continually adapt to remain lifelong learners. The author also emphasizes the importance of developing technology skills in college coursework so that students are marketable and employable in cross-disciplinary and complex work environments. Ożadowicz (2020) examined the instructional shift from traditional engineering instruction in engineering courses to online instruction during COVID-19. They assert that the use of instructional technologies (e.g., mobile devices, web resources) throughout coursework is particularly important to both make learning more interesting and in line with the "contemporary, dynamically changing reality" and to "develop students' skills" for the future workplace (p. 17).

Faced with the rapid transition to online teaching in Spring 2020, educators were forced to adopt new technologies and develop new technological skills. Studies have found that educators' new technology skills altered their relationships with digital technologies for teaching and learning, increasing their confidence (Beardsley et al., 2021; Vergara-Rodríguez et al., 2022). After enduring the stress of teaching during the pandemic era, educators acquired motivation, confidence, and proficiency related to using digital technologies for preparing lessons, direct and indirect instruction, and assessing and providing feedback (Beardsley et al., 2021; Vergara-Rodríguez et al., 2022). Despite teachers' increased skills and more positive beliefs, some scholars are cautioning against using information and communication technologies in teacher education as they were used during the pandemic. For example, Smith et al. (2021) suggested that we need to find ways to incorporate technology critically and reflectively to model good teaching in teacher education because the pandemic was an unprecedented event that forced us to change without much preparation, planning, and digital experience (Kamenetz, 2020; Sun et al., 2020). Effective use of technology in education requires training and practice (Koehler et al., 2013). Therefore, teacher educators need to help future teachers learn to effectively use digital technologies for meaningful teaching and learning in both emergency and standard teaching conditions.

While there are studies that have explored what college students have gained and lost as they worked individually during the COVID-19 pandemic (Ferdig and Pytash, 2021), there is little understanding of what they gained and lost while collaborating virtually with colleagues in another discipline. Collaboration has been identified as one of the most critically needed skills in higher education (OCED, 2017a) and more specifically, engineering (Jonassen et al., 2006) and education (Ronfeldt et al., 2015). Both fields require skills for working virtually and it is important to understand what college students learned from collaborative teaching and learning online during the pandemic, how they learned those skills, and what connections they made between their learning and their preparation for their professional workplaces that are increasingly shifting online. The findings can not only help educators understand how a rapid shift to online learning affected collaborative learning in a cross-disciplinary project, but they can also help us consider how online collaborative projects can be designed and used to prepare education and engineering students for the virtual workplace. They can help educators anticipate what students may learn from a virtual cross-disciplinary collaboration and how they may respond effectively to such an experience. Therefore, this study examines the educational experiences of these college students, including their perceived learning and affective responses, as they collaborated in a virtual environment to teach engineering to elementary school students.

Theoretical framework

In this study, we employed SCT (Bandura, 1986) to understand the engineering and education students' experiences as they worked in teams throughout the Spring 2020 semester to produce and teach upper-elementary students engineering lessons. The framework functioned as a lens to explain how college students' experiences were affected by the mid-semester change in assignments as a result of the COVID-19 pandemic and the transition to online learning.

Social cognitive theory. Bandura (1986) developed SCT as a means to frame an individual's learning experience in a social context, suggesting that people make sense of the world through social interactions. He identified three factors—environmental, personal, and behavioral—that interact and influence each other through a triadic model of reciprocal determinism, where each factor both acts on and is acted on by the others (see Fig. 1). The direction and strength of the interaction between these factors vary depending on the context. According to Schunk and DiBenedetto (2020), behavioral factors are associated with a person's choice of activities, persistence, and achievement, while personal factors reflect individual learner characteristics associated with a person's beliefs, cognition, perceptions, emotions, goals, confidence, values, outcome expectations, and attributions, and environmental factors refer to the context in which behaviors occur, including both physical and social environments. The purpose of this paper is to understand engineering and education students' personal learning experiences: what they believed they learned (or did not learn) and how they felt about their experiences. As such, it focuses heavily on personal factors within Bandura's (1986) framework.

Application of the SCT. This study applies SCT in a virtual context. The following sections outline work that has been examined using the SCT framework in virtual settings and throughout the COVID-19 pandemic. We draw from this literature throughout the current study; however, we move beyond these works as we specifically examine how students' working virtually in interdisciplinary teams perceived their learning and emotions following the full transition to online learning and teaching.

To understand virtual team performance. SCT has been used as a theoretical framework to understand the performance of virtual teams. For example, Staples and Webster (2007) identified best practices for virtual team members and found that the adoption of these practices affected team members' performance and attitudinal outcomes and that the adoption of these practices was

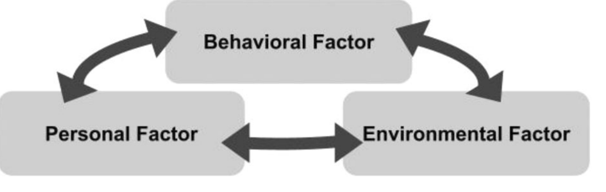


Fig. 1 Bandura's triadic model of reciprocal determinism. This figure shows the bi-directional nature of the three factors within the SCT model-behavioral, environmental, and personal. As something within one factor changes, it may likely result in changes within the other factors as well.

even more important for virtual teams than it was for teams working face-to-face. The practices focus on four central team needs: effective communication, sharing knowledge, using time well, and developing team spirit. Showing the connection to the SCT framework and highlighting the interaction between two personal factors, the researchers found that team members gained confidence (first personal factor) through their interactions with each other which then influenced their perceptions of their team effectiveness (second personal factor). Drawing upon SCT, Jackowska, and Lauring (2021) examined how environmental and personal factors mediate the effect of working virtually on a group of individuals. They found that both the virtual work context (i.e., social settings, spatial locations, time zones) and the personal context (i.e., individuals' cultural backgrounds and perceptions regarding virtual work) need to be considered when assessing the effect of virtuality on group behavior. In other words, environmental and personal factors influence student behavior and the nature of these factors in online settings may differ from face-to-face settings. Accordingly, it is important to study how the SCT framework applies to virtual social contexts.

To understand college students' experiences during the COVID-19 pandemic. There are few studies from around the world that have used SCT to explore what college students experienced during the pandemic. Kinsky et al. (2021) found challenges in adapting to the sudden pedagogical shift due to the pandemic in their study of 295 students from two university campuses in communication courses, impacting self-efficacy, interaction, and motivation. However, students recognized potential future career benefits from skills acquired during the pandemic, highlighting COVID-19's influence on university learning. El-Sayad et al. (2021) observed the impact of academic self-efficacy on behavioral and emotional engagement for college students from Egypt, and that perceived usefulness significantly influenced emotional and cognitive engagement. In a study of 80 students in social science education from Indonesia, Rahiem (2021) noted three motivational themes emerged: personal (e.g., challenge, curiosity, self-determination, satisfaction, religious commitment), social (e.g., relationships, inspiration, well-being), and environmental (e.g., facilities, conditioning). Students in this study were primarily driven by consequential aspirations, not controlled motivation or external factors.

Other studies provided insight for post-secondary educators as they plan for and navigate virtual teaching and learning spaces. Poluekhtova et al. (2020) analyzed Russian journalism students' distance learning experiences, revealing the importance of consistent communication among students, professors, and departments for effective online education. Due to this need for constant communication for effective education, the authors concluded that online learning cannot fully replace face-to-face journalism education. Erragcha et al. (2022) perceived the positive impact of social presence on collaboration, satisfaction, and engagement for students in Tunisia. Satisfaction and engagement mediated collaborative learning's influence on academic performance. They recommended designing modules with collaborative activities and interactive social media tools to enhance the e-learning experience. Zhou et al. (2021) explored Chinese undergraduates' perceptions of instructor and peer relatedness, online self-regulated learning, learning gains, and satisfaction. Results showed relatedness positively influenced online self-regulated learning but had no direct impact on learning gains or satisfaction. Online self-regulated learning fully mediated the relatedness-learning gains link and had a serial mediating effect on relatedness-satisfaction via learning gains, with task strategies and goal setting playing key roles. Lastly, Lux et al. (2022) examined two primary preservice teachers' development of engineering education identities during a COVID-19-affected clinical field experience. Contextual factors provided both opportunities and constraints for professional learning, impacting their identity development. Negotiating these factors had the most significant influence on their engineering-pedagogical knowledge and teaching self-efficacy.

In our previous work. In previous work, we examined education and engineering students' virtual teamwork experiences using SCT (Gutierrez et al., 2022). We found that pre-service teachers and undergraduate engineering students found their interdisciplinary partnerships meaningful because they provided them with the opportunity to develop teamwork skills, such as communication and interpersonal skills, which they believed would be valuable in future work environments. SCT was useful in tracing the influences of different catalysts on students' environments, behaviors, beliefs, and learning. We were able to see how students' interactions within their teams changed when they moved online, as well as how their interactions affected the roles they adopted in their lessons, what they believed they learned from the project, how successful they felt they were, and how satisfied they were with the experience (Gutierrez et al., 2022). SCT was employed in this study because we are exploring engineering and education students' learning in a novel online social context. We aim to understand how our decision to shift students' assignments from preparing a face-to-face lesson to preparing an online lesson influenced their personal learning and affective experiences. SCT helps us trace the influence of our decision as it affects environmental, behavioral, and personal factors within students' social learning context. While we are studying student learning and effect and are consequently honed in on the personal factors within Bandura's framework to examine the outcomes of our intervention, we understand that environmental and behavioral factors act as mediators and moderators of personal factors, instigating and impeding student learning, and we, therefore, consider the influence of all three factors on student experiences. We are interested in learning how the interplay of factors influences student learning outcomes so that we can better understand how our instructor decisions shape our students' learning experiences. If we can predict how students will respond to collaborative assignments, and how those responses may differ if students are in a virtual context, we can craft better experiences to prepare students for workplaces reliant on virtual communication.

Research question

This study uses Bandura's theory of reciprocal determinism to consider how environmental, personal, and behavioral factors interacted to create students' new learning realities after the pandemic-induced transition to remote learning. The pandemic context and shift to online teaching and learning affected the experiences of undergraduate engineering and education students as they designed and delivered engineering lessons in a virtual format for elementary school students. Using Bandura's theory of reciprocal determinism to define environmental, behavioral, and personal factors that frame student learning in a social context, the research question for this study is:

> How did a mid-semester assignment change from planning and teaching a face-to-face engineering lesson to developing and delivering an online engineering lesson influence collaborating education and engineering students' perceived learning and affective experiences?

Methods

Research context. Undergraduate engineering students and education students in a university in the southeastern US were teamed together in the context of 3-credit-hour required courses within their respective disciplines to plan and deliver engineering lessons to upper-elementary (4th–5th grade) students. The Ed+gineering project involves three sets of partnering undergraduate courses in a minority-serving institution as shown in Fig. 2. All three collaborating sets of classes were face-to-face courses prior to the onset of the pandemic. However, students left for Spring Break in the Spring 2020 semester and did not return to campus-based courses due to the COVID-19 pandemic, rather, all courses moved online for the remainder of the semester. The changes in planned activities deprived students of face-to-face interactions with peers and elementary students and full access to resources for all participants. About 42% of education and engineering students identified as students of color. This mirrors the university's population (38%) of students who come from underrepresented ethnic groups (ODU, 2023). More often, engineering students identified as male (81%), and education students identified as female (76%). This gender disparity also mirrors the student populations within these disciplines at the institution of study. The following sections explain how the collaborations were reshaped after K-20 instruction throughout the US transitioned online in the Spring of 2020.

Collaboration 1 (C1). Collaboration 1 partnered beginning education students with beginning engineering students to work in small cross-disciplinary teams of 4–6 students. The goal was for each team to create and teach a one-hour hands-on engineering design lesson to 5th graders who would visit the university campus on a day-long field trip. Each team could choose from two design challenges—a humanitarian package drop or a windmill blade. Nineteen teams collaborated in-person over 5 sessions to plan and practice their lessons prior to schools closing in March 2020. In late March, students were informed that all instruction in the university and in the partnering K-12 school division would move online. The project would continue, but they would now have to interact virtually with their teammates, and instead of planning and teaching a face-to-face lesson, they would now need to develop an interactive Google Slides-based lesson that children could interact with independently. The students were provided with a sample virtual lesson and a template for creating their own lesson. As the teams collaborated virtually over the next month, faculty supported students synchronously as requested through individual or team meetings, otherwise, all instruction was asynchronous. All 19 teams' virtual engineering lessons and slideshows were distributed to elementary teachers in local public and private schools.

Collaboration 2 (C2). Collaboration 2 occurred in an afterschool club at a local public school. As part of their coursework, education students enrolled in an instructional technology course led the club for 5th graders interested in technology as part of their coursework. The engineering lesson—a robotics project—was scheduled for the final five club sessions with engineering students from an electromechanical systems class slotted to assist in three of those sessions. The students were grouped in mixed-age and cross-disciplinary teams of one education student, one engineering student, and one 5th grader and tasked with collaboratively designing a functioning bio-inspired robot to address a global challenge (e.g., a robotic butterfly that pollinated plants). Students were provided with Hummingbird™ robotics kits to create their robots. Prior to the school closures, the education and engineering students from each team met in person to learn how to use their robotics kits and plan their lessons. This training phase took place as planned according to the project's design, and was similar to implementations in previous semesters, prior to the COVID-19 pandemic. Like previous semesters, the subsequent teaching phase was also scheduled to take place in person at the local after-school club and was meant to involve college students having to teach robotics lessons face-to-face to elementary students and collaboratively build bio-inspired robots by physically sharing space with them (Kidd et al., 2020). However, when instruction moved online in late March, the students were told the technology club—and thus their project—would also move online using the Zoom platform. Following the transition, each team held their own weekly Zoom meeting. The education student, the engineering student, and the 5th grader worked via

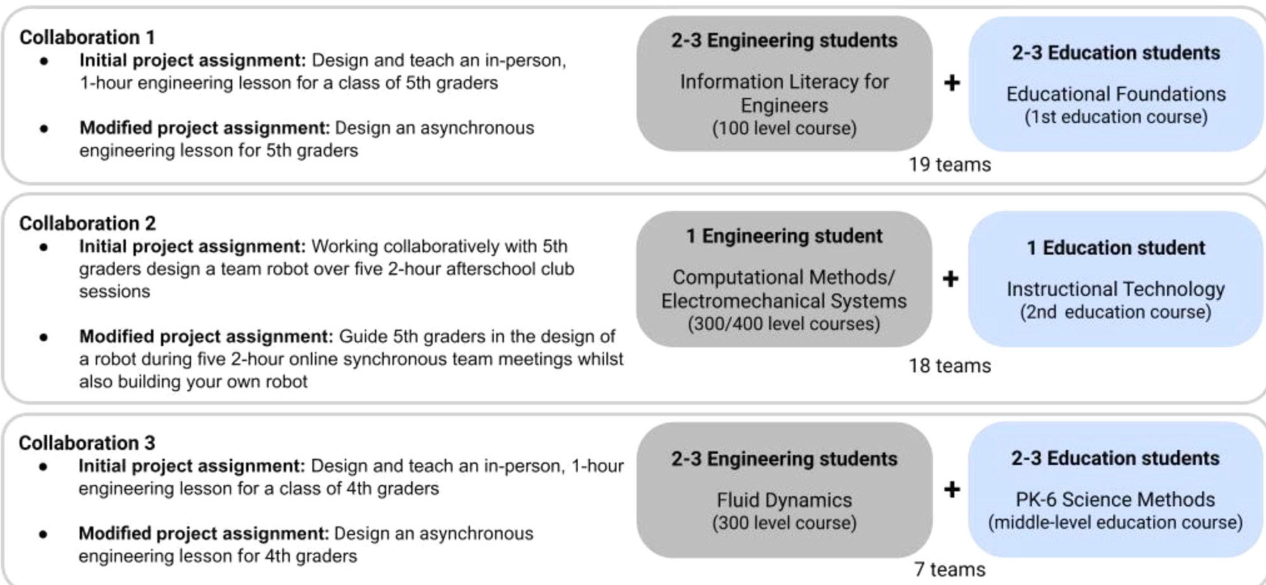


Fig. 2 Ed+gineering engineering and education course collaborations. The top row summarizes Collaboration 1 courses where undergraduate engineering students in Information Literacy for Engineers partner with preservice teachers in Educational Foundations in 19 teams. The middle row summarizes Collaboration 2 where undergraduate engineering students in Computational Methods/Electromechanical Systems partner with preservice teachers in Instructional Technology in 18 teams. The bottom row summarizes Collaboration 3 where undergraduate engineering students in Fluid Dynamics partner with preservice teachers in Elementary Science Methods in 7 teams.

Table 1 Summary of data collected and analyzed per collaboration.

	Collaboration 1	Collaboration 2	Collaboration 3
Written reflections (~30 questions)			
Engineering students	18	15	23
Education students	33	19	11
Focus groups (~20 questions; 30–60 min)			
Engineering students	1 group ($n = 5$)	2 groups ($n = 9$, each)	1 group ($n = 5$)
Education students	2 groups ($n = 4$, each)	4 groups ($n = 5$, each)	1 group ($n = 5$)

Zoom for approximately 2-hours each week to design and code their robots. Due to the geographic separation resulting from students working at home, teams could not collectively build a single team robot. Instead, each team member received an individual robotics kit. The college students' goal was to guide the 5th graders in the design of their robot, but they were also strongly encouraged to create their own robots in accordance with their team's vision to address a global challenge (e.g., ocean pollution). Teams met for 4-5 sessions as needed to complete their robots.

Collaboration 3 (C3). Collaboration 3 was planned as a field-trip model similar to Collaboration 1. Seven teams met face-to-face several times prior to transitioning online. Each team was preparing to design and teach a class of 4th graders at the university campus. These teams visited their partnered 4th grade classes earlier in the semester to introduce engineering as a career and the engineering design process, and to get to know the interests of the students they would be teaching. The 4th graders in the seven participating classes voted on their favorite fluid mechanics-related real-world examples (e.g., jets, elevators, slime) which helped the college students plan their lessons. When instruction moved online in late March, both the university and elementary students' mode of instruction changed. The collaborating faculty members chose to finish the semester in an asynchronous format, supported by flexible virtual office hours, as requested. We revised the main course project from planning and teaching a face-to-face lesson to developing an asynchronous interactive Google Slideshow engineering lesson but maintained the direction to design the lesson with their elementary class's interests in mind. Once completed, the virtual lessons were sent out to the partnering teachers, as well as to a handful of other project-affiliated teachers for wide distribution.

Data collection and analysis. This study examined engineering students' and education students' project experiences through short answer written reflections and focus group interviews at the end of the Spring 2020 semester. Separate focus groups for education and engineering students were held and led by project members who were not the students' instructors. Table 1 provides additional information on the reflections and focus groups for each collaboration.

Students were asked a wide variety of questions related to their project experiences in the reflections and focus groups, however, only responses directly linked to the shift to remote teaching and learning were analyzed for this study. This included responses to pandemic-related questions—such as, "Did you learn different knowledge or skills preparing for an online lesson than you learned preparing for a face-to-face lesson?" Additionally, since students' responses to general reflection questions often referred to virtual experiences, pandemic-related responses to non-transition-specific questions were also coded (e.g., "What did you learn?, What did you learn about engineering?, What did you learn about teaching?").

A theoretically valid protocol for content analysis of the reflections and focus group data was developed following the steps outlined by Rourke and Anderson (2004). To begin, we identified the purpose of data analysis (i.e., to uncover the influence of the assignment change from planning and teaching a face-to-face lesson to developing and delivering an online engineering lesson on college students' personal learning). Secondly, we cursorily reviewed the data for each collaboration and then built a codebook, categorizing students' responses into the three factors of SCT. Within each factor, we identified common themes and sub-themes that emerged from the data, and finally, we negotiated codes that would be used across all collaborations.

The individual student is the unit of analysis for this study, thus, anything external to the student was coded as an environmental factor. All responses that were specifically tied to the assignment change or related faculty actions (e.g., providing supplemental resources that supported the development of the online lessons) were coded as environmental factors as well. The factors within the SCT were operationalized for this study accordingly: (1) behavioral factors include a student's actions, (2) environmental factors include a student's external condition or situation, and (3) personal factors include a student's internal conditions (e.g., perceived learning, affective responses). We tested the established codes on a subset of both engineering and education students' reflections and focus groups to ensure all data could be coded using the draft codebook. We established inter-coder reliability by coding a subset (10%) of student data together, through a process of negotiating codes and adding exemplar guide quotes within the codebook for clarity until we came to a 100% agreement on the coding scheme. Utilizing the final version of the codebook, each of the three lead authors independently coded the remaining data from one of the three collaborations.

Findings

Education and engineering student experiences were examined using SCT (Bandura, 1986) following the shift in their major course assignment from delivering a hands-on elementary-level engineering lesson face-to-face to delivering it virtually. Each undergraduate student represents a unit of analysis to help explore how the changes in their assignment and subsequent online lesson production altered their learning experiences and to facilitate mapping connections between environmental, behavioral, and personal factors within the SCT model. This study explores students' perceptions of their learning and effect as they completed their revised engineering lesson assignment after the COVID-19-induced Spring 2020 transition to online learning.

Bandura's (1986) SCT model demonstrates that environmental, behavioral, and personal factors interact to frame student learning in a social context. Our research question focuses on personal factors within the SCT model, that is, students' internal conditions. Within the domain of personal factors, we looked specifically at their perceived learning and affective responses. We examined how the change in assignment influenced students' perceptions of what they learned and their affective states. Accordingly, the findings are presented as they relate to these two personal factors: (1) students' perceived learning from making lesson modifications and (2) students' affective responses. Put another way, the findings are grouped to illustrate the two main ways students indicated their learning changed as a result of the shift in their assignment. Students perceived learning new and

Table 2 Organization of the findings.

Students' perceived learning from making lesson modifications	Students' affective responses
Students reported learning the following modification of lessons for online delivery: • Skills for teaching online • Professional skills (e.g., effective ways to interact virtually) • Educational technology skills • STEM-related content and pedagogy • Missed opportunities for learning	Students reported affective responses primarily associated with two themes: • Preparation and Delivery of Virtual Lessons • Faculty Support

different things when they modified their lessons for online delivery, and they reported that modifying and delivering their online lessons evoked a variety of emotional responses. We identified themes within each of these two personal factors (see Table 2) and explored these in detail in the sections below. Woven throughout the findings are students' discussion of the benefits and challenges they experienced designing and teaching their virtual engineering lessons, and the benefits they perceived for the elementary students receiving the lessons.

Students' perceived learning from making lesson modifications. In SCT, perceived learning is one of many personal factors that interact and affect student learning (Bandura, 1986). Perceived learning refers to an individual's subjective evaluation or belief about their own learning and the knowledge or skills they have acquired. Perceived learning can influence future behavior and motivation, as individuals who perceive successful learning experiences are more likely to engage in similar learning tasks in the future. When instructors changed the project assignment following the pandemic-induced shift to online learning, undergraduate students were tasked with modifying their lessons to enable elementary students to work independently on engineering design challenges in their own homes. Collaboration 1 (C1) and Collaboration 3 (C3) students had to design asynchronous lessons where the children would work without any live assistance from the undergraduates. Collaboration (C2) students designed their lessons for synchronous delivery, where the undergraduates would provide remote assistance via Zoom. The changes in delivery mode required the students to modify the content of their lessons. C1 and C3 students had to replace activities planned for face-to-face implementation with interactive slideshows and videos. For example, a C1 engineering student explained,

> Our original intent to engage the students was to make them put a napkin on their face and try to blow upwards to teach them about wind power and how windmills function. However, after the online transition we simply provided them a short video to engage on what windmills are and how they work.

Students tried to find ways to maintain the rigor of their lessons in the virtual context. For example, a C3 education student explained how her team included "interactive probing questions" to help the children "think critically about the engineering design process" and "reflect on what they did and how they can improve." C2 students had to redesign activities to maintain student engagement over Zoom. A C2 education student shared that rather than lecture her 5th grader, she kept him engaged by giving him editing access to her Google Slideshow so they could create content together.

The college students often described learning experiences that stemmed from making modifications to their lessons. An education student learned about the "need for alternative lesson plans and how flexible one must be to be a teacher," after making these changes mid-way into the semester. Education students were able to learn more about how to teach, what they were teaching, and how to use technology to best teach their lessons following the assignment shift to virtual instruction. Engineers took a different perspective on the shift to online teaching and learning as explained by a C2 student, "doing this via Zoom was a big challenge, and engineers are problem-solvers by definition, so it presented a problem to be solved."

Students described learning different skills, and in many cases, more skills than they would have had they not had to modify their lessons for virtual delivery. In particular, students most often reported learning *skills for teaching online*, *professional skills*, such as effective ways to interact virtually with partners and stakeholders (i.e., parents, clients), and *educational technology skills*, in addition to learning *Science, Technology, Engineering, and Mathematics (STEM)-related content and pedagogy*. Additionally, *missed opportunities for learning* were shared by students.

Skills for teaching online. Students often reported learning strategies for teaching online and education students in particular acknowledged these as critical skills for the future. As explained by a C2 education student,

> I do not think virtual teaching is something that is going away any time soon…teaching on Zoom really prepared me to teach without being there to physically guide the student. As much as I was upset when we were forced online, I think it truly benefited me in a way I might not have otherwise seen.

The experience of teaching engineering virtually, and in particular, teaching children to design a robot over Zoom, increased education students' confidence to teach online generally. As one C2 education student explained, "I was forced to teach *everything* instead of doing it for her or showing her directly." Successfully teaching a hands-on lesson in a subject that was new to them helped students feel confident in their ability to teach other, more familiar subjects. One C2 education student explained that "getting the chance to teach this, crazy, complicated concept over Zoom, kind of makes me like, 'Okay, if I can teach this stuff over Zoom, I can teach, like, reading and addition and the more classic elementary concepts.'" An engineering student in C3 reflected on the benefits of hands-on learning for the elementary students and the opportunity to show children that "a classroom is anywhere. It does not have to be a classical classroom but anywhere a person happens to be." Another C3 engineering student became more aware of the importance of "adding in fine details and asking lots of probing questions" in virtual, asynchronous lessons.

Professional skills. Students reported learning communication skills beneficial for their future careers. The C2 students were required to interact with parents to coordinate Zoom sessions and the acquisition and safe use of project supplies (e.g., box cutters, hot glue guns). As a C2 education student explained, "Our parent interactions *greatly* increased; that may have been one of the biggest growth areas for me." A C1 engineering student shared that he "learned […] how to communicate better online, which should help as everything becomes more and more virtual." Other engineering students elaborated on the project experience as a way to enhance their virtual communication skills in preparation for their careers. A C2 engineering student further explained that the pandemic has created "more scenarios where telework and work-from-home jobs are more prevalent for engineering and technical professions. […] This was a good learning process to see how to work within the constraints that come with this type of communication."

Educational technology. Students in all collaborations shared how they learned to use educational technologies and quickly adapted as technology issues emerged. For C1 and C3 students, this included learning how to record and embed audio/video files in Google Slides presentations. Students across the collaborations explored technological tools for elementary student collaboration, interest, and engagement. Many of the undergraduate students who were concerned about engaging students via an asynchronous presentation reported learning to use pedagogical strategies and educational technologies to keep students' attention. This was not limited to education students. Engineering students were able to see firsthand the myriad ways technology can support teaching and learning. A C1 engineering student said, "I learned how to use an app called bitmoji [to make] the presentation a little bit more child-friendly." C2 students learned to leverage the teaching features of Zoom (e.g., screen sharing, whiteboard) and how to juggle between multiple tech applications (e.g., Google Slides, Make Code, brainstorming apps) while in a Zoom session in order to utilize the best tools for the content they were teaching and the pedagogical strategies they were employing (e.g., using a collaborative sketch board over Zoom to draw out ideas for their robot). They also created resources using technologies (e.g., screencasts) to help the children learn to work independently in an online environment.

STEM content and pedagogy. Students' STEM content learning was impacted both by the transition to online learning in their undergraduate classes and the transition in the assignment to a virtual lesson delivery mode. These impacts were attributable, in large part, to the introduction of new resources. C2 students were given a Hummingbird™ robotics kit to use at home, while C1 and C3 teams were provided with a sample virtual lesson and a Google Slideshow template to guide the creation of their lesson. These resources, particularly the kits, profoundly shaped education and engineering students' learning experiences by directly influencing their behaviors and indirectly affecting their learning and confidence in teaching engineering to elementary students.

The Hummingbird™ robotics kits enabled C2 students to spend more time preparing for their lessons by experimenting with the components on their own schedule. The C2 students frequently shared that exploring their robot's hardware and software at home had a positive impact on their confidence and learning. As one engineering student described, "I think the robot-building activity helped improve my knowledge of programming. My understanding of coding with the micro-bit improved because I had to research and learn how to use it to make the demonstration robot I wanted." Another engineering student agreed,

> I think that if there'd been no school closure, I would not have been driven to properly learn the coding, as someone else would have done that instead. Therefore, working in isolation caused us all to learn more than we would have otherwise.

Having their own kits also enabled the college students to build individual robots, which enhanced their ability to teach their elementary school partners and increased their perceived STEM learning (e.g., learning how to code). As a C2 education student explained, "My own learning was affected by making my own robot because I could see exactly how I made certain mistakes." Students reported benefiting from working in their small teams over Zoom to create similarly themed robots. A C2 engineering student explained how building his own robot helped him be a more effective teacher—"We all made some version of the same robot, and it was helpful, especially as a teaching tool, to have something to point to and say, mine works like this." Another engineering student added,

> I really liked that I had the ability to build my own comfort robot because beforehand we wouldn't have been able to have that, we would all build one together. So I did enjoy that I was able to build my own and kind of show what I could do because I want to go into animatronics. So this would go along with what I wanted to do.

However, the provision of kits also caused difficulty for some students. Because it was logistically difficult and expensive to provide all club participants with the most recent version of the Hummingbird™ robotics kit, some engineering students received a kit from the previous generation. Additionally, a few engineering students chose not to collect a kit at all. In either case, it was harder for these students to actively participate within their teams, causing frustration for teammates. An engineering student described how having a slightly different kit can "complicate things when you're trying to explain code… you can't really demonstrate anything."

The C1 and C3 students also discussed the influence of the new resources their instructors provided to help the teams convert their lessons to a virtual format. They reported benefiting from the sample virtual lesson and lesson template that was provided to the teams, explaining that it helped get all their team members on the same page. A C1 engineering student explained,

> My team did utilize the slideshow template for our lesson. It was a very helpful resource that gave us a nice outline. It helped us plan more thoroughly and ensure we had all the necessary components. The example lesson that was given to us about prosthetics was great. It really helped the team visualize what our lesson might look like and what standards our work should meet.

Meanwhile, some C3 education students felt the sample lesson and template limited their creativity and autonomy. One student explained how the lesson "should've been more creatively done by us" rather than being just "a prompt for us to fill out" that "doesn't really match idealistically what I would do."

Perceptions of missed learning opportunities. Despite describing many positive academic benefits, the college students reported believing they missed out on certain learning opportunities because they switched to an online, asynchronous lesson delivery mode. C1 and C3 students reflected on missing out on the opportunity to teach their lesson face-to-face with the kids. For example, a C1 engineering student felt he missed the opportunity "to get any feedback from the 5th graders". The C3 students recognized the missed learning opportunity when they were stripped of the chance to witness their elementary students' responses to lessons that they planned in order to address their assigned class's interests. A C1 engineering student acknowledged the "trade-off of the public speaking skill" for other technology skills as he missed the opportunity to "speak in front of elementary students." C1 and C3 education students also lost the opportunity to practice face-to-face pedagogical and classroom management skills. Furthermore, undergraduate students thought they may have been able to receive more intensive face-to-face support from their instructors and engineering student teammates had they not transitioned online. A C2 education student mentioned that she would have learned more skills from a face-to-face setting as she missed out on "the real-time comments and tools that you learn from observing how others teach." Finally, several C2 students believed they would have learned more engineering content and skills and made more sophisticated robots working face-to-face.

Affective responses. In SCT, affect is another one of many personal factors that interact and affect student learning (Bandura, 1986). Affect refers to an individual's emotional experiences and moods and can significantly influence their behavior and learning (Bandura, 1986). Emotions can impact a student's motivation, attention, and overall engagement in the learning process (Bandura, 1977). While students were asked how the transition to online learning and the shift in assignment affected their process and perceived learning, they were asked a few questions about their emotional response to these changes. Nevertheless, students reported a variety of emotional experiences associated with the project and the process of modifying their lessons for virtual delivery. Student affective responses (i.e., comments related to moods, feelings, attitudes, and confidence) related most often to their *preparation and delivery of virtual lessons for elementary students* and to their perceptions of *faculty support*. These two themes (see Table 2) are explored in more detail in the following sections.

Preparation and delivery of virtual lessons for elementary students. Students described affective experiences throughout lesson development and delivery, especially in connection to their interactions (or lack thereof) with the elementary students. The undergraduate students often reported emotional rewards from working with the children and excitement to share their expertize with the elementary students. One C2 education student explained, "I am so happy we were able to continue with the club through Zoom. I loved talking with my student once a week and helping him create his robot." Another C2 student recounted how she received pictures of her 5th-grade partner working on her robot independently, outside of the Zoom sessions, and explained, "It made my heart warm because it made me feel like Clara [pseudonym for her 5th-grade partner] was excited to show me [how hard she was working on] this lesson I had prepared for her." One C3 engineering student explained, "My favorite thing was making the engineering design process video because I could show something that I built and was able to provide a real-world example to someone." A C2 engineering student expressed a sense of satisfaction from contributing to a young person's positive experience,

> I think it was a great feeling to see the excitement of our student, you could tell he was very enthusiastic. He had a few questions for me about engineering and everything. So it's a great feeling to be able to offer that service to someone —to be an inspiration.

Some students reported an increased sense of responsibility for teaching their elementary students because they were isolated from their instructors and other classmates (e.g., while teaching in their small teams via Zoom). For example, a C2 education student said,

> I feel like I actually learned more when this class was put online as it became more one-on-one without an instructor right there to aid me if I got stuck. I feel like this situation forced me to apply everything I've learned about teaching and allowed me to make decisions on the go and overall benefited and enhanced my [5th grade] students' learning experience.

Students reported wanting to provide quality learning experiences for the elementary school students, and that this feeling helped motivate them to make lesson modifications. One C2 education student explained,

> Virtual WoW Club gave me more autonomy than in-person WoW Club. I was able to decide what I wanted my student to achieve, the methods of instruction, what topics I wanted them to explore, and how much time I wanted them to work on it.

Another C2 education student explained how she spent extra time "making sure I had the right definitions, and everything made sense because I didn't wanna go and teach my students something that was incorrect."

Many students described learning benefits for their partnered 4th/5th graders. For example, one C2 student who taught via Zoom, and therefore could not physically assist her elementary student, saw "a new and improved mode of problem solving" which required her 5th-grade partner "to be a little more self-motivated, especially when he became frustrated." Another C2 education student conveyed it simply: "Rachel [5th grader] built her robot completely on her own."

When students described beneficial learning experiences for the children they instructed, these observations were often accompanied by expressions of pride and confidence in their own teaching ability. A C2 education student said,

> Before this class, I knew nothing about coding and programming… After working with my 5th grader and being able to teach someone else who doesn't know anything about coding and programming made me happy. Especially since we were both able to walk away from the class successfully creating a working robot.

Another C2 engineering student described what it was like to see his 5th grader succeed: "[She] would type code in and then a part would move exactly the way that she wanted to … you could see her light up when that happened, and I think, I think that said more than words."

In addition to feeling a sense of accomplishment for the ways in which they helped the children, many undergraduates also expressed satisfaction with their own achievements. After creating his own robot, a C2 engineering students remarked—

> We all had access to the same kit but different materials to build with and as such, we all did things slightly differently. I was able to use my 3D modeling and 3D printing experience to create a robot that was at my level of expertize. My partners both used shoeboxes and other material that they could craft with… It felt really good to be able to model and prototype the robot that we had talked about.

Students had mixed emotions related to the new modality of their lessons. A C1 engineering student admitted that not having to teach in person alleviated her anxiety. On the other hand, some students reported feeling nervous when creating certain aspects of their lessons, such as designing presentation slides for an elementary audience, communicating with students via an asynchronous presentation, or making and presenting videos. For example, a C3 engineering student reported,

> I was least comfortable having to record myself for the slide I was responsible for. I feel more comfortable when I express my thoughts in writing or face-to-face conversations. I feel that when I record myself there's more time and opportunity for others as well as myself to scrutinize and pick apart what I'm saying or doing in the video.

Many C1 and C3 students who did not get to teach their lessons synchronously, were disheartened because they did not have the opportunity to interact with students. For example, a C3 team planned their lesson around an elementary student's love for McDonald's ice cream. The team's members were particularly disappointed they did not get to see the student's reaction to the lesson they created. In the words of a C1 education student, "After the transition online, I lost a lot of my motivation to continue since I would not be able to actually interact with the students in-person or even see them complete the project."

Some students who presented synchronously also reported frustration in developing and delivering their lessons. Negative emotions were often connected to the many challenges of teaching online (e.g., poor internet, demonstrating how to manipulate robotic components virtually). As a C2 engineering student recalled, "sometimes it was hard to explain a concept over webcam that would have been easily demonstrated in person, i.e., 'I think you should put your motor like this.'" Students conveyed a myriad of ways in which elementary school students' personal characteristics (e.g., motivation for the project, interests, ability to focus on an activity for two hours) and contexts (e.g., family support, tech access, ability to work independently outside of meetings) affected their ability to carry out their plans to fidelity which then impacted their perceptions of success. As a C2 education student recalled,

> My Zoom lessons did not go as planned at all. The last three meetings we had, my student was late to every single one, the student had terrible connection with his Wi-Fi multiple times causing it to be very hard to see his work through his camera, it was hard to hear him speak so eventually he had to communicate with us through the chat box. My 5th grade student also seemed very bored at times with our lessons, and I couldn't tell if he wanted to do it or not.

Faculty support. While the undergraduate students reported both joy and frustration from working with their teammates and elementary students, they nearly universally reported feeling supported by the faculty as they developed and delivered their lessons. Students described supportive environments in which instructors facilitated their lesson adaptations by providing prompt, helpful feedback, assisting with technology challenges, and meeting with them as needed. As a C3 education student explained,

> The faculty really gave great advice and made sure… that we were meeting the needs of the [elementary] students. I felt their support was very helpful and necessary; without their help the projects could've lacked in certain areas for the students.

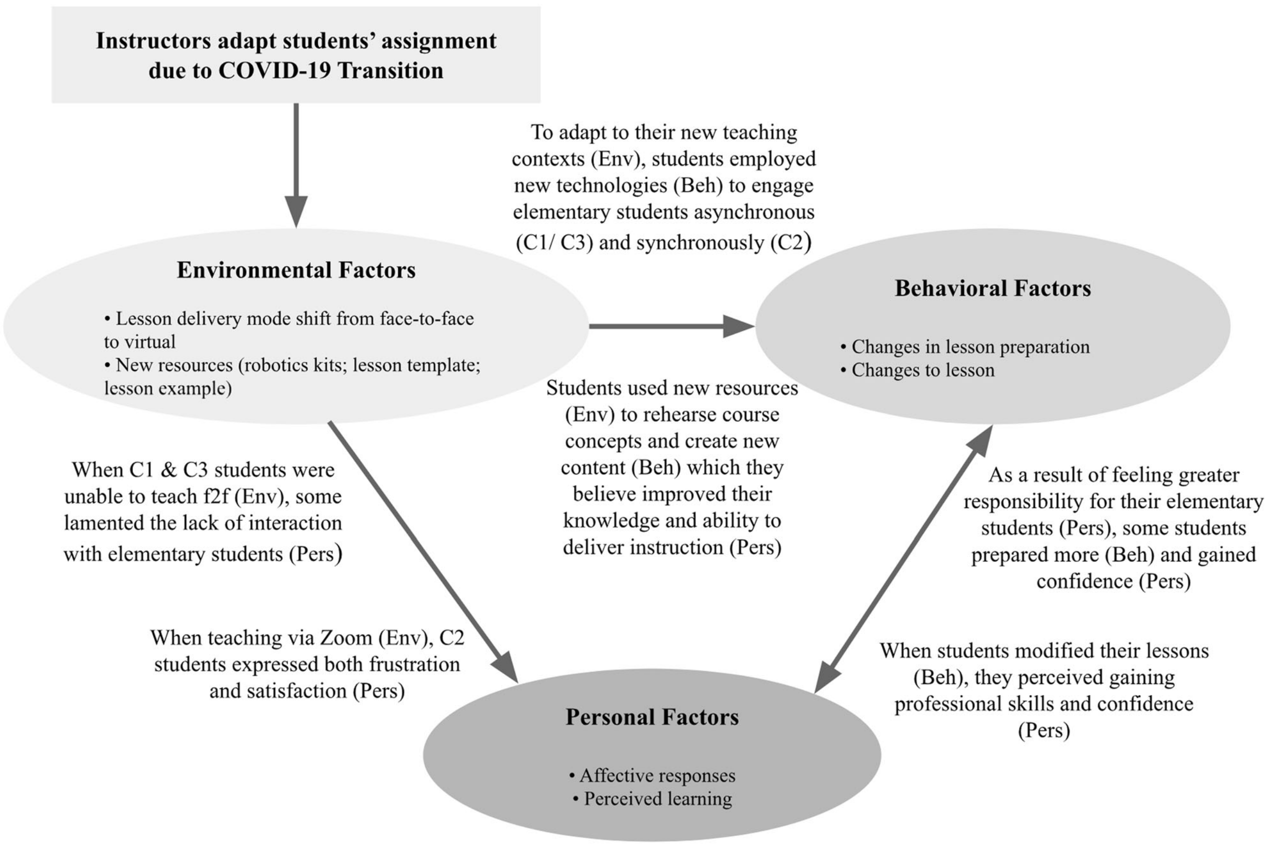
Interestingly, while students reported feeling supported, there was not a perception of increased faculty oversight. As described earlier, several students found the instructional environment to be more autonomous post-transition and explained how their perception of reduced oversight and direction from faculty triggered first a heightened sense of responsibility, and then, motivation for producing good lessons for the children. A few students explained that faculty encouragement enhanced their confidence and willingness to take risks in the autonomous environment. A C2 education student put it this way—

> I think [teaching the robotics lesson online] definitely increased my confidence level and just what I'm capable of learning and teaching technology-wise. Coding was very overwhelming at the beginning, but Dr. [] really encouraged us that it was okay to learn with our students. That we weren't expected to know everything. And I think that that gave me some confidence to, just in my future classroom, to be willing to try out some new things technology-wise, that maybe I'm not 100% sure how it's gonna pan out or exactly how it's gonna go, but to be willing to just try it.

Bringing it all together using the SCT framework. It is clear that the change in assignment from planning and teaching a face-to-face lesson to developing and delivering an online engineering lesson had a profound influence on students' behaviors, perceived learning, and affective states. The instructors' decisions dramatically altered the learning experiences of the participating students. The instructors elected to continue the project, determined the media and mode through which the lessons were delivered, and made available additional resources to support students. While the undergraduates' experiences during the onset of the pandemic were multi-faceted and influenced by factors external to the project, they also illustrate the ways in which our decisions as instructors reverberated across students' environments, behaviors, perceived learning, and affect.

The previous sections discussed the influence of the assignment change on students' perceived learning and affective experiences, two examples of personal factors in Bandura's SCT (1986). In the next section, we apply Bandura's lens of reciprocal determinism to discuss the dynamic interactions between personal, environmental, and behavioral factors. We identify pathways of influence within the model, showing how conditions in one factor triggered conditions in other factors. Figure 3 is presented to illustrate examples of commonly reported pathways between the SCT factors as the undergraduates transformed their lessons for virtual delivery. This figure is not meant to diagram the experiences of all participating students, or to represent all the pathways of influence; instead, it is intended to highlight a few commonly reported pathways that map how the instructors' decisions shaped students' learning experiences. For example, as depicted in Fig. 3, students used new resources provided by their instructors *(environmental factor)* to rehearse course concepts and create new content *(behavioral factors)* which in turn, caused students to perceive gains in their knowledge and ability to deliver instruction *(personal factor)*. Here it can be seen that the instructors' action to provide resources served as an environmental factor that triggered certain student behaviors. Students' behaviors—reviewing course material and creating lesson content for their elementary students—then had a direct effect on students' perceptions of their knowledge and ability to complete their work. As a result of delivering lessons that they perceived to be successful for the elementary children *(personal factor)*, undergraduates felt satisfied with the project and their learning *(personal factor)*. Accordingly, we can trace the pathway of influence from an environmental factor (new resources) to a behavioral factor (reviewing and creating content) to several personal factors (perceptions of improved ability, success, and satisfaction). In this way, it becomes clear how instructor decisions can lead to student learning and affective outcomes.

Patterns of influence were observed between all factors; however, some pathways were more commonly observed than others. In particular, students were more likely to discuss the



Note. The arrows indicate the direction of the most commonly observed pathways of influence between the factors: the environmental factors of the new online instructional modality and new educational resources commonly prompted changes in students' behaviors and personal responses; reciprocal influences were seen between students' behavioral and personal factors.

Fig. 3 Sample pathways of influence within the SCT triadic model of reciprocal determinism. As instructors adapted the undergraduates' assignment following the COVID-19 transition, the environmental factors were altered. This caused ripples throughout the SCT model as students switched gears to change the structure and context of the lessons (behavioral factors). This change in their assignment (*environment*) also caused changes in students' affect (e.g., disappointment, frustration) and perceived learning. These changes were also observed between the behavioral and personal factors as students took on more responsibility in lesson design and implementation, gaining confidence and skills.

ways in which they responded to their new environmental conditions than they were to discuss the ways in which their behaviors and perceptions shaped the environment. Expounding on the prior example, the new resources the students received to help them modify their lessons (i.e., individual robotics kits to use at home and lesson templates upon which to model their Google Slides-based lessons) acted as new environmental factors that shaped their behaviors: upon receiving the kits, the C2 students practiced coding at home so they would be better prepared for their lessons; when they were given the lesson template and sample lesson, C1 and C3 students met in their teams to determine how to make their team lessons match the new model. These behaviors typically went on to influence students' personal factors, like perceived learning and affective responses, but the behaviors were not as likely to have a reciprocal effect on students' environments. Or, more succinctly, students, particularly those who did not teach lessons synchronously, were not as likely to report observing how their behaviors affected their external environments. Meanwhile, reciprocal influences between personal and behavioral factors were commonly reported by students. For example, when students modified their lessons (*behavioral factor*) and felt they were successful *(personal factor)*, they often reported feeling pride, a sense of having learned something new, and/or confidence in their instruction (*personal factors*). In this way, we can see how a student's behavior (modifying their lesson) influenced multiple personal factors (perception of learning, pride, confidence), and how one personal factor (perception of success) influenced others (pride, perception of learning). Another similar example is shown in Fig. 3. As a result of feeling greater individual responsibility for their elementary students in the virtual context than they felt in the face-to-face context *(personal factor)*, some students shared that they studied STEM content more deeply than they would have in the face-to-face lesson context and that they prepared additional lesson materials for their virtual lesson that they would not have prepared for a face-to-face lesson *(behavioral factor)*. These additional actions led some students to evaluate their lessons as successful *(personal factor)*.

The findings uncover pathways of influence showing how individual students' learning and affect were influenced by the instructors' shift in the assignment (*environmental factor*). Here we can see how the instructors' decisions shaped student behavior (how they modified their lessons) (*behavioral factors*), perceptions of what they learned from those modifications (*personal factors*), and how they felt about their lesson experiences (*personal factors*). The interplay among these environmental, behavioral, and personal factors within Bandura's model of reciprocal determinism is further examined below with the ultimate goal of understanding how instructors can influence these interactions through the design of class assignments and activities—particularly in online course experiences—to replicate these gains, especially those that seamlessly transfer to students' future careers.

Discussion

To organize the discussion, we first consider the influence of discipline on undergraduate student pathways and outcomes, examining implications separately for education and then engineering students. Next, we consider the implications for post-secondary educators, discussing how instructor decisions influenced students' learning experiences through the SCT framework and providing suggestions to prepare education and engineering students with professional skills to navigate the new virtual work and learning environments. We focus especially on the influence of the lesson delivery mode and corresponding social context, exploring how the resulting environmental factors influenced students' learning experiences as seen through the lens of SCT.

Implications for undergraduate students. While developing online lessons was challenging for most students, the great majority of the undergraduates reported positive academic and affective outcomes. In many cases, students reported learning more than they expected, and in some cases, more than they believed they would have learned had their lessons remained face-to-face. However, the benefits students reported translate differently into their future workplaces as the skills required on the job are different for teachers and engineers. Accordingly, it is important to highlight the differences and the commonalities in the implications of these findings based on student discipline. For instance, teaching skills are very relevant for education students, but not as relevant for engineering students. Conversely, cross-disciplinary collaboration skills are very critical for engineering students but not as much for education students. Virtual communication skills, meanwhile, are important for both. The students' discipline is also a personal factor which serves as a lens through which students evaluate their experiences. As such, a student's discipline affects what experiences they pay attention to and how much they value those experiences. Accordingly, the common SCT pathways can differ by discipline.

Education students. The assignment to plan and teach a lesson was immediately applicable to education students and had clear connections to their professional development needs. It is not surprising then that education students reported learning many skills related to teaching, including lesson planning, managing student engagement, utilizing educational technologies to support student learning, and skills specific for teaching online. Specifically, we can see how the skills learned during the project helped education students be prepared to teach online, use educational technologies, and develop the flexibility required of today's teachers.

The shift in the project assignment to either teach the elementary students via Zoom (C2), or to enable elementary students to work on engineering design challenges in their own homes asynchronously and independently (C1 & C3), had the unexpected benefit of helping prepare education students to teach via multiple modalities. Increased demand for K-12 online education (Rice and Deschaine, 2021; Smith et al., 2021; Sprague et al., 2022) means that future teachers must be prepared to teach in virtual settings. Teacher preparation programs and K-12 schools alike are now calling for this preparation. As Zhao and Watterston (2021) indicated, K-12 teachers can no longer rely simply on their expertize in teaching face-to-face but should be prepared to teach successfully in both synchronous and asynchronous learning environments moving forward.

The shift to a virtual lesson emphasized educators' need for technological pedagogical knowledge (Koehler and Mishra, 2009), or knowledge about how to use technology to teach, as well as technological pedagogical knowledge specific to teaching engineering. Education students across the collaborations shared how they learned to use educational technologies. C1 and C3 students spent more time learning how to create multimedia that would engage students working independently and clearly convey content they would not be able to explain in real-time. So, not having a live student audience for the lesson presented a challenge for C1 and C3 students, but it was also an opportunity to master skills for asynchronous teaching and virtual collaboration. Students in C2 explained that they learned to engage learners in real time via Zoom, switching between platforms (e.g., the MakeCode coding platform and Google Slides) as needed and quickly adapting as technology issues emerged during Zoom sessions. In both lesson delivery modalities, the pandemic forced these future teachers to examine technology as a tool for teaching and learning, echoing what Beardsley et al. (2021) and Vergara-Rodríguez et al. (2022) found, it altered their relationships with technology and advanced their digital skills.

An education student explained how the change in lesson delivery mode made them realize the "need for alternative lesson plans and how flexible one must be to be a teacher." Koehler and Mishra (2009) argued that teaching requires a great deal of flexibility and quick thinking from different domains including "student thinking and learning, knowledge of subject matter, and increasingly, knowledge of technology" (p. 61). Having to change tactics mid-semester helped prepare education students for the dynamic environment of K-12 classrooms, where upheaval in a day's planned events is commonplace.

Education students were framing their perceived learning benefits in relation to the skills they perceived to be beneficial for their future careers as teachers. So, while they discussed learning how to use educational technology or STEM content, they most often discussed these in terms of how the skills or knowledge would help them be more effective teachers. Likewise, when education students discussed gaining confidence, they were most often discussing the extent to which the experience helped them feel confident teaching. In comparison to the engineering students, the education students reported learning more skills beneficial to their profession as a result of the assignment shift. The SCT pathways were similar between the education and engineering students with most pathways initiating from environmental factors and subsequently influencing student behaviors and personal factors. However, since education students reported positive learning experiences more often than engineering students as a result of the assignment change, there were more instances of education students moving through the commonly reported SCT pathways.

Engineering students. While teaching a lesson to elementary students can help prepare engineering students for outreach activities they may be expected to perform in their future positions with engineering firms, a more obvious and immediate benefit of the project is an improvement in engineering students' ability to collaborate virtually, and more specifically, collaborate virtually with non-technical audiences. The engineering students seemed to understand that the post-pandemic shift in the workplace will require them to be able to adjust to a virtual job site. Furthermore, they saw their project experiences helping to prepare them for this new reality.

Engineering students generally framed their perceived learning in relation to skills they perceived beneficial for engineering generally (e.g., additional practice coding and designing a robot due to using their own robotics kit at home) or skills they anticipated would help them succeed in a virtual work environment (e.g., learning to communicate with their team via Zoom). Engineering students also mentioned learning new skills, for example creating multimedia content, but did not necessarily explain how they interpreted their usefulness. Interestingly, some engineering students saw the lesson adaptation for online delivery as an engineering design challenge itself and appreciated the exercise of trying to devise a viable solution. The SCT pathways commonly reported by the engineering students were largely the same as those reported by the education students, however, the engineering students reported fewer perceived learning benefits as a result of the change in lesson modality, therefore there were fewer instances of engineering students moving through commonly reported SCT pathways.

Implications for post-secondary education and engineering educators. When comparing our two undergraduate student populations, we saw differences in the number of responses within the themes we identified for each SCT factor, but no differences in the commonly reported SCT pathways. However, when comparing participants by collaboration, we observed differences in the reported pathways. Students who taught synchronously (C2) reported learning experiences that followed a different, additional pathway that was not reported by students who created asynchronous lessons (C1/C3). The difference in delivery mode (synchronous or asynchronous) had the most dramatic effect on student learning experiences as seen through SCT, however, we were also able to trace the influence of other assignment design decisions on SCT pathways. The fact that assignment design appeared to exert a larger influence on student learning experiences than student discipline demonstrates the power of instructor design decisions in shaping student learning. The learning environments that instructors create for their students can influence student learning through multiple pathways. We move now to a discussion of these instructor decisions, the learning pathways they evoke, and the resulting implications for post-secondary educators.

Different pathways observed for C2 (Synchronous) vs. C1/C3 (Asynchronous) lesson delivery. There were important differences in the structure of the lesson assignment for the collaboration models. In Collaborations 1 and 3, the students were assigned to create an asynchronous lesson using Google Slides. In Collaboration 2, the students were assigned to teach a multi-session lesson to one or two 5th graders via Zoom. The differences in the structure of the assignment shaped the students' social contexts. The C2 college students interacted with their elementary students in real-time via Zoom whereas the C3 college students met their elementary students in person before the transition to online learning but never interacted with them again, and the C1 never interacted with elementary students at all. The differing social contexts meant there were different environmental factors that impacted students' perceived learning and affect. The different environmental factors influenced the students' outcomes and the SCT pathways through which the learning and affective experiences occurred.

Some pathways were prominent in the responses from students in one collaboration and largely absent in students from another. Students in C1 and C3 created lessons for asynchronous delivery and unfortunately were unable to receive feedback from elementary students on the success of their lessons. Accordingly, students were unable to see the influence of their behaviors (i.e., the modification of their lessons) on their target audience. This change in lesson modality, from a face-to-face lesson to an asynchronous lesson, in essence, inhibited a learning pathway from forming. Since the elementary students were not part of the C1 and C3 students' environment, they were not an environmental factor influencing their learning. The college students received no feedback from their intended lesson audience and therefore could not see how their behaviors shaped their (intended) environment, the children. Furthermore, the college students were not able to experience effects based on the children's reactions to their lessons. The absence of these pathways reduced the opportunity for learning for C1 and C3 students.

In contrast, the C2 students taught their lessons synchronously via Zoom and as such, the elementary students were part of the college students' environment. The C2 students were able to see how their behaviors affected their environment and the children. Accordingly, new learning pathways emerged. The children in the after-school club acted as an environmental factor, influencing the C2 students' behaviors and personal learning outcomes through their responses to the lesson activities. Whereas C1 and C3 students rarely reported how their behavioral and personal factors influenced their environments, the C2 students witnessed the elementary students' responses to the lessons and regularly discussed them. The elementary students' responses provided critical information that enabled the college students to assess their own successes. These assessments greatly influenced the college students' perceived learning and affective experiences. Referring back to Fig. 3, in C1 and C3 the common pathways were *from* environmental factors *toward* behavioral and personal factors. There were no reciprocal pathways leading back toward environmental factors. However, in C2, the pathways into environmental factors opened. Based on elementary student reactions, the education and engineering students were able to see the ways in which their actions influenced the 5th graders. And the 5th graders' responses, in turn, influenced the college students' behaviors and perceived personal learning. In short, the synchronous delivery modality created new feedback loops inside the model, enabling reciprocal influences. These reciprocal pathways can be visualized as double-sided arrows between the behavioral and environmental factors and between the personal factors and the environmental factors (see Fig. 4). In contrast, in the commonly reported pathways from C1/C3 students, these arrows are one-sided, pointing only away from the environmental factors, as the students had limited ability to see how they influenced their environments.

Beyond enabling the college students to receive real-time feedback from the children, the design of Collaboration 2 opened other opportunities for learning. It enabled them to practice communicating with additional stakeholders and to better understand the needs and circumstances of those stakeholders. Students across both disciplines and all three collaborations reported benefitting from the opportunity to practice communicating virtually, however, education students in C2 appreciated the practice they gained communicating with parents, a group with whom they typically have little experience. The Zoom-based lessons allowed them to not only practice communicating with parents but to understand how educational technologies can facilitate this process. Zoom also provided windows into students' home environments, an opportunity that, prior to the pandemic, was usually only obtained through an actual home visit. Interacting in real-time and with this new window into the children's home enabled both education and engineering students

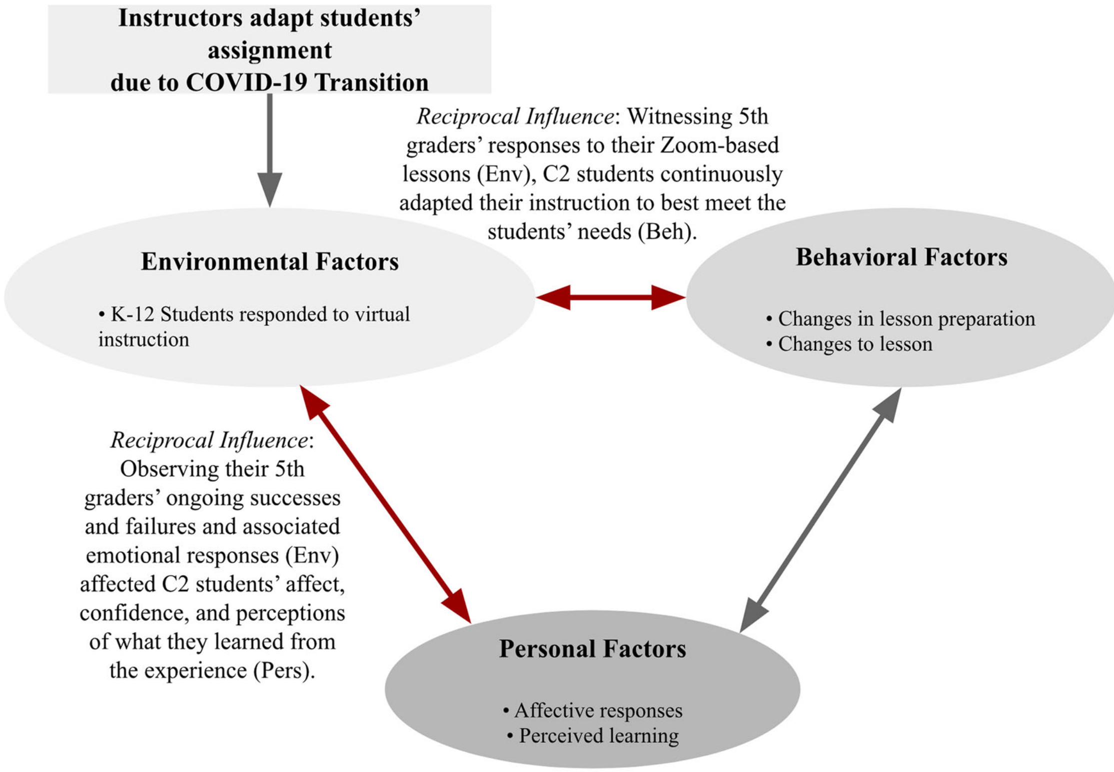


Fig. 4 SCT pathways of influence commonly reported by C2 students. The reciprocal nature (see red arrows) of the model was evident through the reflections of the Collaboration 2 students. As the teams taught the 5th graders over Zoom (environmental factor), they adjusted their instruction to meet the needs of their 5th graders. As the 5th graders failed and succeeded building their robots (environmental factor), the undergraduates also experienced affective responses (*personal factor*), which then altered their confidence and perceived learning (*personal factor*).

in C2 to witness the importance of personal characteristics (e.g., motivation for the project, interests, ability to focus on an activity for two hours) and contexts (e.g., family support, tech access, ability to work independently outside of meetings) on the children's ability, as well as their own ability, to participate successfully in the virtual environment. The college students reported noticing how the children's behaviors differed when the context switched from face-to-face to online and how some children were better positioned than others to succeed in the online environment. The college students also noted how their own behavior and the behaviors of their teammates differed in the new context as well. This relates to Jackowska and Lauring's (2021) study examining the mediating influence of environmental and personal factors on individuals working virtually. They found that contextual factors (e.g., setting) and personal factors (e.g., cultural backgrounds, attitudes toward working virtually) must be considered when evaluating the effect of working virtually on group dynamics. In other words, environmental and personal factors influence student behavior, and the nature of these factors in online settings may differ from their nature in face-to-face settings. For example, a student who is outgoing in the face-to-face school setting may be reserved in a Zoom-based virtual setting. Teachers and engineers working virtually will need to consider how the online context is affecting their own and their client's ability to communicate effectively. This project gave both groups the opportunity to engage in this analysis.

The modality of the engineering lesson was but one example of the many considerations educators may encounter when designing course assignments and activities. As seen in the findings, many faculty actions, including the support and resources they provide, have a substantial influence on student learning outcomes. Accordingly, it is important for teachers and engineering educators to consider the implications drawn from our findings as they ponder their assignment designs.

Best practices for undergraduate student populations. Students found teaching an engineering lesson virtually to be pedagogically and technically challenging but described feeling satisfied after making successful lesson modifications. They also recounted the difficulties of collaborating virtually. Vielma and Brey (2021) argue that faculty should organize opportunities for undergraduate students to be empowered by and supported through academic and social challenges in virtual learning experiences. Online remote work has become a new norm in the shifting landscape of the workplace (Caringal-Go et al., 2022; Carroll and Conboy, 2020). Ndubuisi and colleagues (2022) suggest faculty develop projects that provide practical experiences for college students to develop skills that parallel the real-work environment. Engineering educators must address online collaboration skills to prepare students to work in industries that have shifted online and collaborate in primarily virtual contexts (Kolm et al., 2022; Ndubuisi et al., 2022; Vielma and Brey, 2021). As engineering education researchers (e.g., Kolm et al., 2022; Ndubuisi et al., 2022; Vielma and Brey, 2021) continue to examine the ways in which engineers work in teams, both in the face-to-face and virtual environments, faculty in higher education should help ensure that undergraduates are provided with opportunities through the structure of their courses and assignments to practice scenarios that mirror real-world telework situations.

The most potent influence stemming from an instructor's decision was the change in delivery modality, however, there were many examples where instructional decisions influenced the learning experiences of students. While the learning environment was also shaped by repercussions of the pandemic that were outside of the instructors' control (e.g., students being geographically isolated from their peers, and unstable Internet connections), instructors still made decisions to attenuate these circumstances (e.g., requiring students to meet virtually with their partners). Several decisions reflected effective instructional practices and had positive impacts on student learning and led to productive SCT learning pathways, so we offer these as suggestions for other educators. These include the aforementioned selection of real-world professional tasks, the design of assignments to support student autonomy, the inclusion of authentic and engaged audiences/clients, faculty support through feedback, and the provision of resources (e.g., physical materials, and digital templates) to bolster student success. Each of these suggested practices is outlined below.

Autonomy plus accountability: Students in this study were required to work on assigned tasks on their own, in their own spaces (*environmental factor*), because of the remote learning restrictions imposed by the pandemic. Findings suggest that a regulated amount of productive struggle (Murdoch et al., 2020) can be useful to help develop confidence through the development of content and procedural knowledge. Students, particularly those in C2, felt an increased sense of responsibility (*personal factor*) due to their geographic isolation as they were asked to teach on Zoom from their homes, away from their classmates and instructor. Some students reflected on this forced autonomy and indicated that because they may not be able to rely on others, as they would have been able to in a face-to-face teaching environment, and because they wanted to provide their fifth graders with effective and enjoyable learning experiences, they felt as if they needed to invest additional time (*behavioral factor*) to learn how to build and code their robot so they could teach these new skills and content to their elementary student(s). Others explained that the increased autonomy allowed them the freedom to make more decisions about their robots or how they structured their lessons. For many, this extra effort and initiative increased their perceived learning related to engineering, coding, and/or teaching (*personal factor*). Moving forward, educators should explicitly design assignments that encourage autonomy and initiative and leverage external accountability measures, like an audience (Ling et al., 2023), to incentivize student engagement. As Deci and Ryan (1985) remind us, when students have a sense of control and ownership over their learning, they are more likely to be motivated because they feel personally invested in their education.

High levels of interaction with authentic audiences: Researchers agree that student interaction is key to an effective online class (Cavanaugh, 2005; Cavanaugh et al., 2009; Friend and Johnston, 2005) and that emotions and social relationships help drive learning (Immordino-Yang et al., 2018). In this study, students' interactions with all of the individuals involved in the project—elementary students, their college peers, and the faculty (*environmental factors*)—seemed to contribute to the undergraduate students' affect and learning (*personal factors*). Students' affective responses (*personal factors*) were often associated with preparing and delivering their lessons (*behavioral factors*). Positive emotions were typically linked to interacting with the children, including feeling pride or a sense of accomplishment for contributing to a young person's learning, whereas negative emotions typically channeled frustrations associated with the limitations of teaching online, such as poor Internet or an inability to physically assist the children. As discussed above, C2 students expressed motivation and an enhanced sense of responsibility for the project when it shifted online because they felt beholden to their audience of elementary school students. We recommend educators create real-world tasks that employ authentic audiences in order to prepare students for their professional fields and also to invite engagement. Our findings suggest the presence of an audience opens new pathways to learning through feedback and affective engagement and that virtual audiences too can exert this powerful influence on student learning. Furthermore, when educators examine, and invite their students to examine, the affective implications and academic ramifications of learning and working online, it can help them anticipate and account for students' affective responses to collaborating in future virtual settings. In short, students will begin to understand and prepare for the fact that not everyone interacts the same way in a virtual environment that they do in a face-to-face one.

Faculty support: During and following the pandemic, Luburić and colleagues (2021) examined and responded to the challenges higher education faculty faced with student engagement and found that "the teaching staff attitude proved to be one of the most influential factors for student engagement" (p. 1633). Students in that study particularly noted the importance of communication and faculty responsiveness to promptly address student concerns (Luburić et al., 2021). Additionally, Luburić and colleagues (2021) caution faculty against overburdening students who are already in high-stress situations. In our study, faculty tried to adhere to these recommendations for responsiveness, organization, and perceived workload by meeting with teams as requested, providing ample feedback, creating a template and sample lesson to clearly communicate expectations, and providing additional resources to promote student success and reduce stress and anxiety (*environmental factors*). Additionally, we tried to reduce stress and anxiety by applauding students' willingness to try out new technologies and pedagogies and to tackle a task of which the outcome was uncertain, rather than emphasizing a perfect outcome (*environmental factor*). We did this in C2 for example, by not attaching a grade to the success of students' robots or Zoom lessons, but instead asking students to reflect on their experiences. The pandemic and online lesson modality created a sense of uncertainty for both faculty and students, but this may have had a liberating effect in that both parties were venturing together into unknown territory, unsure of what the result would be, and therefore somewhat free from the traditional expectations associated with teaching a lesson. For the majority of students, strategies utilized for faculty support led to positive affective responses (e.g., confidence, risk-taking, calmness) at the end of their course (*personal factor*). For faculty designing learning activities that require students to engage in new skills (such as learning to collaborate online, and preparing/delivering an online engineering lesson), we recommend supporting students' risk-taking by lowering grade-based stakes and providing ample time and resources for them to learn and practice the new skills.

Providing resources: Providing resources for students, particularly for students learning virtually, is essential for student learning. The students in our study reported significant learning benefits from the resources provided by the instructors. Whether digital resources (e.g., Google Slides templates, sample interactive Google Slide lessons) or physical resources (e.g., individual Hummingbird Kits), the instructors' efforts to supply students with proper resources (*environmental factor*) after the shift online went a long way toward earning student buy-in. The resources also enabled high-quality online learning experiences and increased students' perceived learning (*personal factor*). As an example, students in C2 often attributed their increased learning in robotics to the fact that their instructors provided individual kits for them to explore and design (*behavioral factors*) in their own homes, at their own pace. However, course modality can affect the usefulness of resources and some online resources may not measure up to those available in face-to-face settings. For example, Mishra et al.

(2020) reported faculty members' "grave concerns over the [simulated] laboratory activities" used in courses moved online during the pandemic (Mishra et al., 2020, p. 6). In our study, the C2 students' robotic kits created a communication challenge. Students had to hold robotic components up to their cameras and this limited their ability to convey positioning information (e.g., "put your motor like this"), point out important details, and demonstrate interactions and functionality involving multiple elements. For educators with the luxury of planning a virtual activity in advance, rather than shifting rapidly to one mid-semester, we suggest considering the appropriateness of resources for virtual teaching and learning contexts, and learning what resources will be employed in professional settings once students graduate. If students know they are using resources that are similar to those they will utilize in their professional fields, they are likely to invest time in learning to use those resources.

Limitations. As with all educational research, there are limitations associated with the current study. The study was couched within a large four-year NSF-funded study where engineering and education students worked collaboratively to design and teach engineering lessons to elementary students. All the course instructors were part of the study and as such had extensive experience working together and teaching engineering. This shared history and experience helped them successfully transition the collaborations online. Additionally, one of the instructors teaches instructional technology and was well-versed in digital tools for developing online lessons. This expertize was shared and undoubtedly affected the students' ability to succeed in their task of designing online lessons. Furthermore, the onset of the pandemic in Spring 2020 and the rapid transition to online learning affected students, faculty, and their families in both profound and mundane ways. Examining that influence is outside the scope of this study. As such, we cannot assume that college students who may be engaged in similar within-discipline or cross-discipline team-based projects in a different university or outside of the pandemic influence would have similar outcomes. Our particular context of study, however, illuminates how a cross-disciplinary project provided undergraduate students an opportunity to grow personally and professionally during an online learning experience, even during the tumultuous onset of the pandemic. The lessons learned can be translated to undergraduate classrooms beyond the backdrop of the COVID-19 pandemic. Additionally, the SCT, while valuable for the exploration of the social learning context within the current study, is complex. We did our best to identify relationships within and between factors—particularly those related to personal factors for this study—however, we are unable to pinpoint all the influences as there are likely to be factors outside of the class project that impacted student experiences. Despite these limitations, we believe using a qualitative approach to answer our research question allowed us to provide voice to our participants and rich descriptions of their perceived experiences within and among the three SCT factors.

Conclusion

With the increasing need to prepare future professionals for online work environments, we believe the mid-semester shift of Ed+gineering's project during the pandemic provided undergraduate education students and engineering students with the opportunity to practice collaborating, teaching, and learning in a virtual context. SCT illuminated how the instructors' decisions to shift the students' major course assignments from designing and teaching an engineering lesson from face-to-face to online, affected the undergraduate engineering and education students' perceived learning experiences and affect. The findings revealed dynamic interactions between personal, environmental, and behavioral factors, shedding light on how these factors influence the success and satisfaction of virtual collaborative learning experiences.

As undergraduate students prepared and taught virtual engineering lessons to elementary students, they perceived gaining new skills and knowledge. Some students lamented missed learning opportunities, like practice presenting face-to-face, but overall, students reported learning more than they expected, and in some cases, more than they believed they would have learned had their lessons remained face-to-face. Students reported learning professional skills, such as communicating with various stakeholders (i.e., parents, clients, elementary students) in virtual settings, teaching and presenting online, and leveraging educational technology to facilitate online communication, as well as learning STEM content, like coding and the engineering design process.

However, we acknowledge that there are different sets of professional skills required for education and engineering majors. Since the skills that teachers need for their jobs can be quite different from those of engineers, it is important to delineate the different needs of the two populations and how aspects of the project addressed each. For example, stakeholder communication looks different for engineers than it does for teachers. Preservice teachers found more value in learning how to communicate with parents, while engineering students seemed to benefit more from communicating with people outside their discipline and developing skills to translate complex concepts to non-technical audiences. Additionally, skills for delivering synchronous instruction are very relevant for education students but not as much for engineering students in their future careers. Conversely, cross-disciplinary collaboration skills are very critical for engineers but not as much for teachers. However, professional communication skills are essential for both.

Contribution to the field. This study contributes to a better understanding of the complex dynamics at play in online collaborative learning and offers insights for educators and instructional designers to enhance virtual learning environments. With regard to the contributions of this study, an expansive library of prior work has focused on developing teamwork skills (face-to-face and virtual) in engineering education. Thus, research on the development of virtual teamwork skills is not new for undergraduate engineering students. While there are many studies focused on developing virtual collaboration skills for engineering students, some even specific to the COVID-19 pandemic (e.g., Wei et al., 2023), the interdisciplinary, asynchronous, and service-learning nature of our study is unique. For engineering students, having elementary students and their families as stakeholders, and educators as collaborators, brings a new dimension to their learning that other studies have not examined.

The findings from this study provide insight for all educators, including those involved in teacher and engineer preparation programs, as they contemplate course assignments to prepare students for their future workplace. We believe the decisions we made as instructors helped make our COVID-adaption successful. We recommend education and engineering faculty provide undergraduate students with opportunities to communicate and work virtually toward a common goal within a team and organize experiential learning opportunities that align with future careers and work environments, including virtual or hybrid workplaces. The shift to online learning and teaching during the pandemic provided the opportunity for engineering and education students to learn professional skills and STEM content in a new, online environment. Based on the gains reported by the undergraduates, we believe that cross-disciplinary virtual team projects may be a successful strategy for helping college students build competencies in virtual collaboration and communication.

While the majority of undergraduates in the current study mentioned gaining knowledge and confidence for teaching engineering and coding virtually, the authors concur with other scholars (e.g., Kamanetz, 2020; Smith et al., 2021; Sun et al., 2020) that preparation to communicate, teach, and work in a digital environment should not be viewed as a one-and-done experience. The COVID-19-induced transition to online learning may have served as a springboard for professional online learning experiences, but instructors must continue to find ways to increase students' professional skills and confidence for working in virtual settings.

The rapid shift to and continued demand for remote working has 'normalized' technology-driven workplace practices (Carroll and Conboy, 2020). Organizations were forced to respond rapidly to the changing workplace with "little time to train or reflect on introducing and normalizing new work practices and the role technology plays" (Carroll and Conboy, 2020, p. 5). Since the onset of the pandemic, scholars have begun to explore the ways in which higher education can provide support for the learning, productivity, and affective well-being of individuals. The current study adds to this body of knowledge by considering how virtual collaborations in professional preparation courses can help prepare students for the new tech-driven workplace. Given that this study occurred in the Spring of 2020 as the world rapidly transitioned to remote working and learning, and students' motivations and circumstances were affected by this unique time period, future work should examine the effects of interdisciplinary virtual collaborations on undergraduate students' professional preparation and readiness for the virtual workplace during planned online course experiences outside of the pandemic context.

Data availability

The datasets generated during and/or analyzed during the current study are not available from the authors due to data security measures promised in our participant consent forms approved by the Old Dominion University Institutional Review Board (IRB) #1249767-15 and #1451315-20.

Received: 29 March 2023; Accepted: 8 November 2023;
Published online: 20 November 2023

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Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant Nos. 1821658 & 1908743. Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors would like to acknowledge Dr. Stacie Ringleb for her contributions to the Ed+gineering Project, particularly in the implementation of Collaboration 1. The project team would also like to acknowledge the determination and efforts of our undergraduate engineering and education students who participated in this project, particularly as we were all working through the unprecedented COVID-19 pandemic. Lastly, we would like to thank the elementary teachers and their students who engaged with our undergraduates and the lessons they created.

Author contributions

All the authors jointly supervised this work.

Competing interests

The authors declare no competing interests.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study. All participants gave their informed written consent.

Additional information

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