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Undergraduate Engineering and Education Students Reflect on Their Interdisciplinary Teamwork Experiences Following Transition to Virtual Instruction Caused by COVID-19

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Abstract: This study explores undergraduate engineering and education students' perspectives on their interdisciplinary teams throughout the rapid transition to online learning and instruction from a face-to-face to a virtual format. In this qualitative study, students' reflections and focus groups from three interdisciplinary collaborations were analyzed using the lens of Social Cognitive Theory. COVID-19 created a dramatic change in the environment such that the most immediate and direct impact on students' experiences was on the environmental aspects of Bandura's triadic reciprocal determinism model, which then triggered behavioral and personal responses to adapt to the new environment. Subsequent evidence of reciprocal effects between environmental, behavioral, and personal factors took place as students continued to adapt. Results suggest that the modifications made to transition the project fully online were meaningful experiences for students' learning and teaching of engineering through teams. This interdisciplinary partnership provided both pre-service teachers and undergraduate engineering students with the opportunity to learn and practice content and professional skills that will be essential for success in future work environments.

Keywords: interdisciplinary teams; engineering education; pre-service teacher education; partnerships; social cognitive theory

1. Introduction

Ed+gineering is a National Science Foundation (NSF) funded program that partners undergraduate engineering students and pre-service teachers (PSTs) (i.e., students in a teacher preparation program) in small interdisciplinary teams to teach engineering lessons to elementary school students. In March 2020, as most schools and universities in the US shifted to online teaching due to COVID-19, Ed+gineering also had to adapt its hands-on engineering activities to a virtual format. The education and engineering courses in which the undergraduates were enrolled transitioned from face-to-face to online delivery, and thus the delivery mode for the lessons for the elementary students had to transition as well, moving to either synchronous or asynchronous online instruction. The transition to online learning affected many aspects of college students' experiences, including their collaboration with their peers and the learning associated with their team interactions.

While much is known about online engineering education [1], little is understood about how the Spring 2020 mid-semester emergency transition to online learning affected K-20 students' experiences learning engineering. Moreover, there is a lack of student voices in the literature, and few descriptions of how students managed the challenges of transitioning online and how they perceived the impact on their learning during this unexpected shift.

As COVID-19 continues to reshape education, it is critical for educators, in both pre- and post-secondary environments, to understand how students were impacted by the transition and how hands-on engineering experiences can be supported in virtual environments. This study examines how the COVID-19 context and shift to online instruction influenced engineering students' and PSTs' learning experiences and team dynamics as they worked in a cross-disciplinary context to adapt and deliver engineering lessons to elementary school students in a virtual format.

2. Background

This paper focuses on the interdisciplinary collaborative experiences of future engineers and teachers as they transitioned to online learning at the onset of the COVID-19 pandemic. In the following section, we ground the work in relevant literature on teaching and learning engineering in online settings, especially the challenges of supporting students' teamwork in a virtual context.

2.1. Teaching and Learning Engineering Online during the COVID-19 Pandemic

After COVID-19 forced schools to shift online unexpectedly, studies that investigated the transition's impact on teaching and learning in higher education settings, and specifically in engineering education, slowly emerged. A plethora of recent articles (e.g., [2–6]) have examined the ways in which universities have adapted to meet the instructional needs of their students. O'Dea and Stern [4] led a special issue in the *British Journal of Educational Technology* where they summarized findings from seven included studies. Notably, the studies suggest that "simply moving teaching content and activities from face-to-face to online environments will not work. They need to be redesigned to suit online learning," and that use of technology in the COVID-19 shift online is critical; however, "technology on its own will not address the educational needs and challenges staff and students face in online environments," rather pedagogical approaches should be designed and used effectively for the specific learning platforms (p. 440). Relatedly, Barr et al. [7] shared how course instructors made many modifications to adapt to online teaching, some of which worked well (e.g., weekly online multiple-choice quizzes, flipped classroom strategy, and links to additional materials) and others that did not (e.g., group activities, faster pace). Reports enumerated logistical challenges, such as lack of infrastructure (e.g., computer hardware and internet access/connectivity) for learning/teaching engineering online, while students expressed a lack of motivation, engagement, and communication with instructors in the Zoom environment [8]. Rassudov and Korunets [9] noted the major challenge of preparing future engineers to operate hardware that can simply not be made available to students at home. In a study about the impact of the COVID-induced migration to online instruction for clinical courses (i.e., nursing, medical sciences, biology, and chemistry), Jeffries et al. [3] shared that some "educators [. . .] made use of items available to [university] students at home, such as a cup of coffee to teach the principles of specific heat capacity" (p. S105).

Regarding teaching modality, most educators opted for either asynchronous sessions accompanied by interactions based on email, forums, or chat or synchronous sessions to replicate the interaction of face-to-face settings [5,6]. However, students reported low satisfaction and felt overwhelmed by those modalities for various reasons (e.g., Zoom fatigue, lack of interaction, and dynamic learning), categorically proposing the reduction of the academic workload in general [6]. Thus, "the process of adaptation to virtuality was not taking place in the best conditions, at least with regard to students" [6] (p. 217). To understand students' fatigue, educators first need to understand that as much as they were forced to look for new strategies and technologies to adapt the transition to online teaching, students have also been forced to adapt to those new modalities and instructions. As a result, they were required to do additional time management, discipline, and organization to meet those new learning modalities [5]. While there are studies that have examined how students manage their personal learning, there are few that examine their learning experiences in a team context during this unexpected shift.

Studies represented in O'Dea and Stern [4] also emphasized the specific needs of learners in virtual spaces, particularly the need for "quality communication and social interactions" as these are important "to build an inclusive online learning environment" (p. 440). Social interactions may be inhibited in online settings [10,11], and some studies reported impediments to group projects due to difficulties coordinating schedules and learning new software for online meetings [7,12]. On a positive note, García Aretio [2] argued that it is possible to form "affective and emotional ties" with their peers and instructors in online settings (p. 15). As a result, researchers emphasize interaction, especially between the student and the teacher, as one of the central elements of online education [5,13]. Vielma and Brey [12] saw this time as an opportunity to train students in the best practices for remote collaboration as engineering work is becoming increasingly global, requiring virtual communication. Relatedly, Ed+gineering's research during this period found that interdisciplinary teams of education and engineering students were able to develop and hone communication and collaboration skills during a virtual engineering lesson project [14]. Continuous team communication and collaboration in a time of imposed isolation became an important source of emotional connection [2] as well as an opportunity for interpersonal skill development in a virtual setting.

2.2. Teamwork in Engineering & Engineering Education

Although engaging in collaborative work as part of courses has been linked to enhanced learning outcomes [15,16], the most significant benefit of teaching teamwork skills in an academic setting is their transferability to the workplace [17]. The growing complexity of the global economy demands increased cooperation and coordination between people with diverse expertise [18]. Thus, a workforce equipped with teamwork skills is critical to face the rapidly changing and global nature of the business context [19]. In particular, teamwork and communication skills are recognized as essential competencies in engineering practice [20–22] and in other disciplines [18,19,23], including teaching [24]. Furthermore, recent research indicates that effective teamwork results in higher quality outcomes and products [25].

Considering the need to prepare future engineers who can collaborate effectively across geographic space and academic disciplines, more research is needed to understand how to best do this. When students learn and collaborate in online contexts, they process the social information available to them [26]. They use this information to develop social structures and patterns of interaction (e.g., signaling a desire to speak) to accomplish their individual and collective goals [11]. While the development of social structures typically takes place seamlessly in face-to-face environments, establishing social connections is more challenging in online learning environments because communication channels are less rich and thereby less suitable for transmitting non-verbal cues [10,11]. Not surprisingly, virtual contexts have been found to be less conducive to establishing trust than face-to-face contexts [27–29]. Accordingly, students collaborating online may face more challenges and/or require additional support structures.

This study explores the team interactions of engineering and education students as they collaborated online to design and teach engineering lessons to elementary school students. While a handful of studies explored the challenges of teaching and learning engineering during the pandemic, there is a lack of student voice in this literature and little focus on how students engaged in teamwork navigated the challenge of transitioning online and how this experience influenced their learning.

3. Theoretical Framework

Social Cognitive Theory (SCT) [30] can be applied to the pandemic timeline to help explain how environmental, personal, and behavioral factors affected students' educational experiences as they navigated the new COVID-19 learning landscape. The SCT framework explores three major factors—environmental, personal, and behavioral—to frame an individual's learning in a social context. In particular, it considers how individuals decide which behaviors to enact in light of their social environment. In addition to environmental factors, students' personal factors, including their past experiences, thoughts, beliefs, and feelings, also affect how they behave [30]. Bandura explains that the influence of the factors is reciprocal, accordingly, students' actions may, in turn, influence their thoughts and emotions. He goes as far as to say that an individual's brain and mental structures can be modified through their behavior [31]. Furthermore, people learn vicariously, by watching others [31], so a person's personal cognitive processes can also be modified by their environment.

Schunk and DiBenedetto [32] explored the SCT framework and identified key components of the three factors. They describe a person's choice of activities, persistence, and achievement as behavioral factors that contribute to one's motivation. Personal factors, on the other hand, reflect individual learner characteristics associated with a person's beliefs and cognition, which are largely intangible. They include an individual's cognition, beliefs, perceptions, emotions, goals, self-efficacy, values, outcome expectations, and attributions [32]. The final group, environmental factors, refers to the context in which behaviors occur, including not only people's physical environment but also their social environment. In other words, the attitudes and beliefs of people inhabiting the same space as an individual can be considered environmental factors.

SCT suggests that personal, behavioral, and environmental factors of the learner interact and influence each other through a bidirectional causation model called triadic reciprocal determinism [31]. Bandura posits that, depending on the context, the direction and strength of the interaction between these factors vary. For example, in face-to-face learning, the physical environment of the classroom, including the behavior of students and teachers, are environmental factors that may have a powerful effect on how a student behaves and feels. In contrast, in an asynchronous online learning environment, the behavior of students and teachers may have far less impact on a student's learning experience. For example, a shy student might be willing to express frustration to his teammates through an online discussion board, whereas he might remain silent in a face-to-face team meeting.

In order to better understand how SCT can help explain the adaptation process in the transition to online learning, consider a scenario where an engineering student is struggling with her robot prototype. Imagine the scenario first in a face-to-face context inside a traditional classroom, and next in an online learning environment. We classify factors that affect the student as she interacts in this space by listing the words *environmental*, *personal*, or *behavioral* in parenthesis after the factor is first mentioned:

In a face-to-face class, a female engineering student is struggling to understand why her robot is not performing as expected. The course instructor, noticing a look of confusion, may walk up to the student, encouraging the student to ask a question (environmental factor) that leads the student to identify the problem (behavioral factor), or the student may look around (behavioral factor) and see her peers working diligently on their own prototypes. There may be a peer beside her in the classroom (environmental factor) with which she compares her design (behavioral factor). Seeing the other student's design may cause her to adjust her own prototype (behavioral factor). If her adjustment is successful, it may lead to an affective response, such as feeling more self-efficacious (personal factor), which helps her persevere in the activity (behavioral factor). If this same student shifts to an online learning environment, she is likely to have a different experience due to the different environment in which she is learning and perhaps her lack of familiarity with that environment (personal factor). She may not be able to see peers working around her (environmental factor); her teacher may not be able to observe her confused expression (environmental factor); and she may not be willing (or have the know-how) to ask a question in the online setting (personal factor). Without feedback from her peers and instructor (environmental factor), the student may not persevere (behavioral factor) and achieve a successful design. As a consequence, she may lose confidence in her ability and/or experience a decrease in motivation (personal factor). In order to successfully navigate her new online environment, the student may need to change her behaviors. If she does not, she may risk failure.

Through this example, it becomes apparent how environmental, behavioral, and personal factors interact and influence each other. Figure 1 illustrates this study's theoretical framework based on Bandura's triadic model of reciprocal determinism.

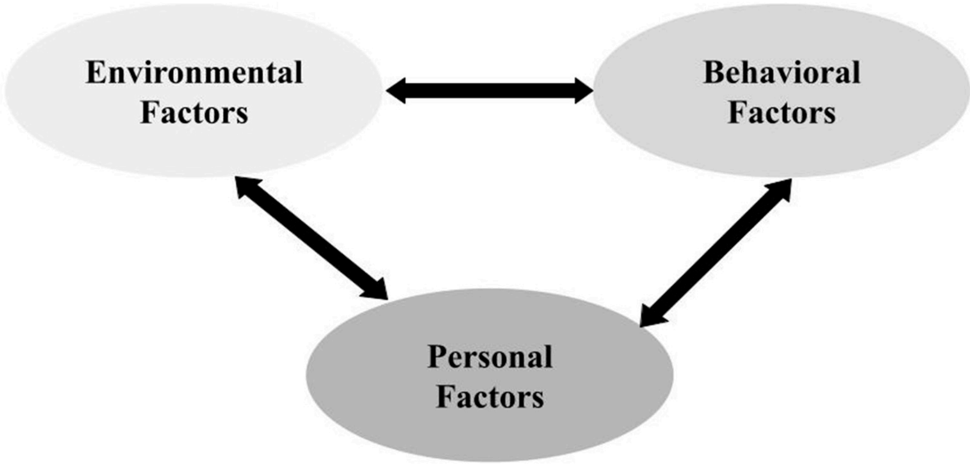

Figure 1. Bandura's Triadic Model of Reciprocal Determinism.

4. Research Question

This study examines how the COVID-19 context and shift to online learning influenced the experiences of engineering students and PSTs as they collaborated to adapt engineering lessons to a virtual format and deliver these lessons to elementary school students. It describes students' experiences through the lens of Bandura's theory of reciprocal determinism to consider how environmental, personal, and behavioral factors interacted to create students' realities post-transition. The research explores how the virtual learning context imposed by COVID-19 influenced students' abilities to function effectively as a team. This includes an examination of how interacting remotely via digital technologies influenced their collaboration, as well as a look into how, and how well, teams adapted from their face-to-face lessons into virtual ones. The specific research question is: *How did the COVID-19 adaptation to a virtual context affect undergraduate students' teamwork experiences?*

5. Materials & Methods

5.1. Research Context

Ed+gineering partnered undergraduate engineering students and pre-service teachers (PSTs) in a minority serving institution in the southeastern US to learn from, and with, each other as they planned and delivered engineering lessons to 4th and 5th graders. The project involved three course-based collaborative projects between two college student disciplines (Figure 2), heretofore referred to as Collaborations. Collaboration 1 (C1) partnered students taking a 100-level engineering class that focused on information literacy with PSTs in their first education course. Collaboration 2 (C2) occurred between engineering students studying electro-mechanical systems and PSTs in an educational technology course. Finally, Collaboration 3 (C3) involved engineering students studying fluid dynamics and PSTs enrolled in an elementary science methods course. To facilitate communication and teamwork, each team of 2–6 college students met outside of class at the start of the project to create a team charter in which they agreed upon team norms. Additionally, each team used a collaborative team Google Site/Drive for sharing team documents. The teams only worked together during the individual collaborations; at the end of each semester, the teams were dissolved. If a student takes a second Ed+gineering course in a subsequent semester, they will be partnered with new team members.

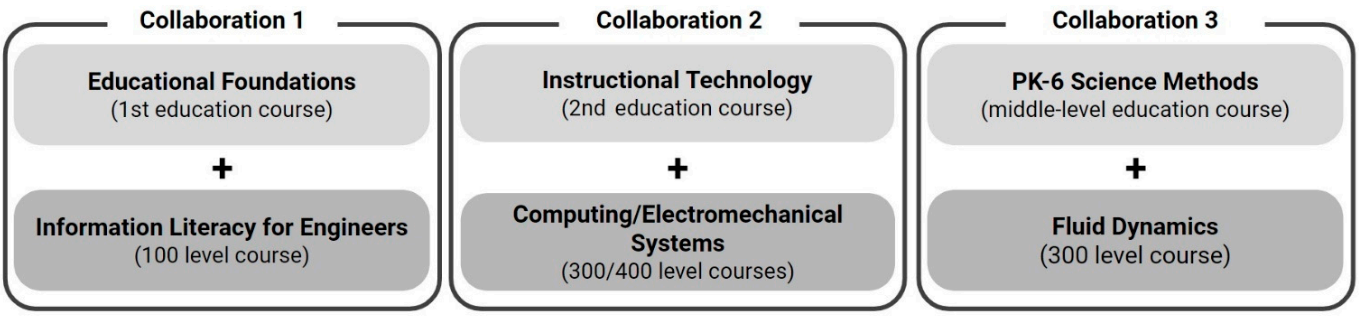

Figure 2. Ed+gineering Participating Courses by Collaboration.

Prior to school closures, all six semester-long courses were being held face-to-face, and the three collaborations were underway based on the original project design. In the following section, we will explain how the study context changed for each collaboration after transitioning online.

5.1.1. Collaboration 1

At the time of the transition to online learning due to COVID-19, the students in Collaboration 1 had already begun working in their small groups of 2–3 engineering students and 2–3 PSTs across 19 teams. They had met several times, both inside and outside of class, to collaboratively prepare for a 1 h face-to-face lesson with about a dozen 5th grade students. The lessons were centered around an engineering challenge, designing either an airdrop package or a windmill. When the pandemic forced the university to move instruction online, teams were likewise forced to move their interactions online and to change the delivery mode for their engineering lessons for the fifth graders from face-to-face to online and asynchronous. To promote interactivity in the asynchronous lessons created in Google Slides, the course instructors encouraged teams to use educational technologies, such as voice recordings, Padlet, Google Forms, etc.

All nineteen teams produced a virtual engineering lesson targeted at a 5th grade audience, and these were distributed to twelve teachers in local public and private schools. While the hope was that the lessons would be shared synchronously during in-service teachers' class sessions, to our knowledge, only one teacher used a lesson this way. One teacher assigned the lesson as an extra credit assignment, while the remaining teachers either posted it as an extra, no-credit assignment, or did not share it with students at all. There is no way to know for certain how many children completed the lesson, but eighteen elementary students submitted a picture and description of their solutions to a contest solicitation embedded within the lesson slideshows.

5.1.2. Collaboration 2

Prior to the university's pandemic-induced transition to online learning, Collaboration 2 (C2) was planned to take place in an after-school technology club for 5th graders. The technology club was led by the second author and her education students enrolled in the collaborating instructional technology course. As part of their class activities, the PSTs were responsible for helping lead each weekly club meeting throughout the entire semester, which met during their course time. The engineering project was planned to span the last five weeks of the club, with the engineering students joining three of the club sessions to help guide the development of bio-inspired robots. The plan was for each team, composed of one PST, one engineering student, and one 5th-grade student, to collaboratively build a bio-inspired robot to address a global challenge. Prior to the transition online, the PST and engineering students had met inside and outside of class to prepare to teach their elementary student partners how to code and build a robot. The PSTs and the 5th graders began their club meetings in person at the school site as planned a few weeks prior to the transition online. This allowed the PSTs and 5th graders time to establish relationships face-to-face. After the transition, the engineering project had to move online, which meant each team of one PST, one engineering student, and one 5th-grade student had to meet online synchronously via Zoom rather than in person at the school. The teams met during the regular club time and persevered in their goal to design, build, and code bio-inspired robots. Each team selected a global challenge and brainstormed ideas for how a bio-inspired robot could help address that challenge. For example, one team developed dolphin-inspired robots with snouts that could scoop up trash from the ocean floor. Most teams met for four or five, 2 h Zoom sessions in order to complete the project. In previous semesters, each team shared one robotics kit and built a single robot. Given that team members were geographically separated as a result of the COVID transition, each team member—PST, engineering student, and 5th grader—received their own individual robotics kit to use, and all were encouraged to build their own robots.

5.1.3. Collaboration 3

There were a total of seven teams in Collaboration 3 (C3). Each team was composed of two to three engineering students and two PSTs. Prior to transitioning online, each team had three in-person meetings to prepare to teach a two-hour face-to-face engineering lesson for a class of approximately 20 4th graders. Unlike in C1, teams in C3 had been able to visit their local partnered 4th-grade classrooms early in the Spring 2020 semester to introduce themselves and the engineering discipline and engineering design process, and to explore the personal interests of the students they would be teaching. Each team presented twelve different fluid mechanics topics (e.g., water parks, cooking, submarines, and slime) and asked their 4th grade students to vote for the top three topics that they would most like to learn more about.

As with C1, teams in C3 were asked to switch gears and prepare an interactive multimedia Google Slideshow following the transition online. However, their lessons were specifically designed to address the interests of the 4th grade classroom they visited. Each team's virtual lesson was sent to their partnered 4th grade classroom teacher, as well as to the other six in-service teachers participating in the collaboration. Unfortunately, only a few elementary students interacted with the lessons, even though the 4th graders were encouraged to enter a contest for participation prizes. The lack of lesson engagement in C1 and C3 was largely due to two factors: (1) teachers were mandated to only use district-produced instructional packets for their students because the district did not want to provide inequitable experiences for students who may not have had technology access, and (2) teachers were already overburdened and stressed due to the rapid shift online.

5.2. Student Participants

Table 1 describes the demographic characteristics of the PSTs and engineering student participants. Approximately 42% of the college students identified as people of color. The majority of engineering students identified as male (81%), and the majority of education students identified as female (76%). The polarized gender disparity between the engineering and education majors and the percentage of people of color in this study mirrors the student populations within the disciplines that are represented and the university as a whole, respectively.

Table 1. Student Demographics (%) for Collaborations 1–3 in the COVID-19 Transition Semester.

		Race/Ethnicity (%)					Gender (%)			Class Standing (%)			
		B	L	W	O	*n*/p	M	F	*n*/p	FY	So	Jr	Sr
C1	UES *n* = 39	21	3	56	8	13	74	13	13	56	33	3	8
	PST *n* = 58	22	3	43	5	26	21	52	27	1	25	51	23
C2	UES *n* = 18	6	11	67	6	6	78	17	5	-	6	44	50
	PST *n* = 21	24	5	67	-	5	5	91	4	-	15	55	30
C3	UES *n* = 28	21	4	61	11	4	93	4	3	-	-	7	93
	PST *n* = 13	31	15	54	-	-	15	85	-	-	-	38	62

Note. UES = Undergraduate engineering student; B = Black; L = Latin (x); W = White; O = Other; n/p = not provided; M = Male; F = Female; FY = First-Year; So = Sophomore; Jr = Junior; Sr = Senior.

5.3. Data Collection & Analysis

Ed+gineering's research, based in the southeastern US, examined changes in engineering students' and PSTs' engineering attitudes, knowledge, and teamwork skills using quantitative and qualitative assessments. To understand students' collaborative team experiences and personal learning as they transitioned to virtual settings, the researchers collected written short-answer reflections and led focus group interviews at the end of the semester.

Reflections included about 30 questions targeting various aspects of the project, such as teamwork (e.g., What roles did you and others in the team play in planning and delivering the lesson? How did the work balance change after moving online?), planning and practicing an engineering lesson (e.g., How did you plan to have the elementary students engage in the engineering design process during your lesson?), and attitudes toward engineering education (e.g., How valuable was this Engineering Lessons Project?). Additional questions (e.g., How did moving to a virtual lesson change the way this project affected you?) were specifically added to thoroughly examine the impact of the COVID-19 transition on students' experiences.

To collect engineering student and PST experiences in a more collaborative setting, we also conducted virtual focus groups via Zoom for both populations and for each collaboration. Focus groups were led by project team members who were not directly involved in the students' collaboration. Each focus group lasted between 30 and 60 min, depending on the number of students in the group. During the focus groups, questions regarding students' overall experiences with the project and specific virtual-related experiences were posed, including "What were the challenges of participating in the Ed+gineering project?" and "How did moving to a virtual environment affect your collaboration with your teammates?" Table 2 provides additional information on the reflections and focus groups for each collaboration.

Table 2. Summary of Students in Each Collaboration and Data Sources.

	Collaboration 1	Collaboration 2	Collaboration 3
Reflections (~30 questions)	18 UESs 33 PSTs	15 UESs 19 PSTs	23 UESs 11 PSTs
Focus Group (~20 questions; 30–60 min)	1 group of UESs (*n* = 5) 2 groups of PSTs (*n* = 4, each)	2 groups of UESs (*n* = 9, each) 4 groups of PSTs (*n* = 5, each)	1 group of UESs (*n* = 5) 1 group of PSTs (*n* = 5)

Note. UES = Undergraduate engineering student.

As the collected data was part of a larger investigation, only responses directly linked to the COVID-19-induced transition were coded for this study. This included responses to COVID-related questions—such as, "How did moving to a virtual lesson change the way this project affected you?", and "Did you learn different knowledge or skills preparing for an online lesson than you learned preparing for a face-to-face lesson?", as well as COVID-related responses to non-transition specific questions (e.g., "What did you learn about engineering? about teaching? about working with other people?"), such as responses that referred to virtual learning or teaching. For example, when stating what they had learned from the project, PSTs often named online teaching practices, such as not filling a slide with too much text.

The research team followed steps to develop a theoretically valid protocol for qualitative content analysis [33]. Following the identification of the purpose of data analysis (i.e., exploring the impact of the COVID-19 transition to online learning on education and engineering students' team dynamics and related learning as they collaboratively developed an elementary-level engineering lesson for online delivery), the three lead researchers built a coherent set of codes by reviewing the data for each collaboration and categorizing students' responses into the three factors of SCT: behavioral, environmental, and personal. Within each factor, they determined emergent patterns, then negotiated common codes to be used across all three collaborations.

Students' actions, conditions/situations, and reflections on their internal conditions were coded as behavioral, environmental, and personal factors, respectively. This study considers the student as the unit of analysis, and therefore, anything outside of the boundaries of the student is considered part of the environment. As a result, a codebook based on SCT constructs was built. The researchers held preliminary tryouts to test the codes on a subset of the data to ensure that all relevant data could be coded within the generated codebook. To establish inter-coder reliability, the researchers coded a subset (10%) of students' reflections and focus groups, negotiating codes and providing exemplar quotes within the established codebook, until the researchers came to a 100% agreement. Using the agreed upon codes and the established codebook, the three researchers independently coded all remaining reflections and focus groups, one researcher for each collaboration.

6. Results

Social Cognitive Theory (SCT) [30] was used to holistically examine the education and engineering students' experiences during the transition to virtual learning as a result of the COVID-19 pandemic. Informed by Bandura's triadic model of reciprocal determinism [30], the researchers considered how environmental, personal, and behavioral factors shaped students' teamwork-related interactions and learning. The individual students were the units of analysis to which the SCT framework was applied; it is their collective voice that the findings and discussion convey. This section attempts to examine how the COVID-induced changes in students' environments influenced their experiences and to uncover common and important relationships within and between the SCT factors. Thus, this study explores the influence the move to online learning had on the college students' teamwork experiences.

The mid-semester transition to online learning led to a rapid shift in team expectations and interactions. First, the goal that the teams were attempting to meet changed. Instead of preparing to deliver face-to-face engineering lessons for elementary students, the teams had to shift gears to prepare for a virtual delivery. Second, the teams no longer had the opportunity to meet face-to-face; all communication had to occur virtually. In addition, informal interactions that may have occurred before, during, and after class sessions were eliminated. Accordingly, students had to find new ways to interact to meet their goal. In sum, the COVID-19 adaptation put significant new demands on teams. Team members had to first come to a common understanding of their new goal and then formulate a plan for achieving the goal within their new virtual context. Thus, the change in the engineering lesson delivery mode and the changes in the university "classroom" environment influenced students' team environments, team behaviors, and their personal learning and affective responses related to these teamwork experiences. The following sections describe how teams' interactions were affected by the changes in environmental factors and what they learned from their online interactions. The interplay among the environmental, behavioral, and personal factors of Bandura's model of reciprocal determinism is also examined here with regard to the changes in team expectations and team environments as a result of the project's transition online.

6.1. Impact of the Online Transition on Team Interactions

Students differed in their perceptions of the impact of the online shift on team interactions. Some students perceived little difference in how they interacted with their teammates, explaining that neither their team environment nor their team behaviors changed much. Others reported positive and/or negative impacts. These students tended to name specific ways in which their team behaviors changed as a result of the online transition.

Students who perceived minimal impact on their teamwork were primarily participating in Collaborations 1 or 3. These students indicated that their teammate interactions changed only slightly because they initially met with their teammates online and continued to do so throughout the semester. They also perceived their team members' work effort and team roles to remain consistent throughout the project. Early in the semester, teams created a charter outlining team norms (e.g., team roles and responsibilities) for how they would successfully collaborate during the semester [15]. Some teams were able to adhere to the norms laid out in their charters, maintaining the original roles and meeting times despite the university's move to online instruction and the alteration in the team assignment. With social structures already in place, these students did not perceive a drastic change in their team functioning post-transition. A PST in C3 described her team's context following the transition online, sharing that, "there were minimal changes to the dynamic of our group. The group and I still stayed consistent with our meetings every Wednesday at 6 p.m. The roles and also productivity maintained the same".

On the other hand, more than two-thirds of responses did report changes in team communication or meetings. Changes related to the frequency of meetings, the roles and responsibilities of the team members, and the technologies used to support team interactions. Many teams reported increased communication amongst team members. This increase was at times attributed to the change in meeting modality and other times to an increase in the workload related to the revised assignment (i.e., planning a virtual rather than face-to-face lesson). Many teams reported needing to increase their formal communication since they were not able to informally check-in before/during/after class as they had done previously. This was especially evident in C3, where the classes had been meeting concurrently in neighboring classrooms. A few teams found they had additional time to collaborate with peers given the elimination of their school commute and the cancellation of other extracurricular activities. Others noted that the virtual format placed greater demands on their time. Some teams explained that prior to the transition, they were able to get work done collaboratively during their face-to-face meetings; however, they did not feel as productive in their online meetings and were left with a significant workload to accomplish outside of scheduled meetings. Most reflections indicated that teams expended additional time and/or effort to prepare for their online lessons and that students perceived this as an increase in their team's workload. Many students found the new expectation to convert their face-to-face engineering lesson to a virtual format confusing and bringing their team to a shared understanding of the new goal took time, especially online. For example, a PST in C1 explained that the challenge of making a virtual lesson was compounded "since we could not meet in person with our team".

Students indicated that they had to re-think the logistics of their lessons as well as the logistics of planning for their lessons. Both C1 and C3 students described changes in the structure of team tasks; rather than working collaboratively to create slide content in real-time, the team would assign specific slides to team members to complete independently.

Students seemed to feel more pressure when designated individual responsibilities. Many students stressed the importance of studying the content they were assigned to teach the elementary students and practicing engineering tasks they were assigned to demonstrate in their lessons. An engineering student from C3 also shared that:

> *"As a result of me having to teach the education students and the elementary students, I found myself looking back at the lessons to ensure my understanding of the topic before teaching it. Thus, I studied more diligently so I could teach the topics."*

For C1 and C3 students who were recording audio and video files to embed in their slideshows, it was important to have accurate information that was well presented. Students reported recording and re-recording their multimedia slides multiple times and feeling anxious about their performance. C2 students, particularly PSTs, were motivated to spend additional time preparing for their synchronous Zoom lessons, so they would feel confident teaching their 5th grade partners, knowing they would not have others (e.g., other classmates, teaching assistants, or the instructors) to rely upon during the live sessions. A PST in C2 was thankful for the additional time she had to prepare for her lesson:

> *"I think that was something that was unique about moving online. It just gave us a lot more time to prepare [. . .] because I was able to code and play with things before the meeting when I had time that I wouldn't have had access to if it were just the normal in-class meetings."*

Many teams reported improvement in their communication post-transition, often because they developed successful new protocols, such as meeting via Zoom prior to teaching lessons (C2). A PST in C2 explained that it actually helped her team better prepare—"I would set up 2 h Zoom meetings for us [her and her engineering partner] prior to each of our lessons [for the elementary students], so that we could make sure we were on the same page and figure out any problems". Some students shared that they became closer to their teammates as a result of facing similar pandemic hardships. When students lost the opportunity to interact face-to-face with their peers and instructors after the campus closed, team meetings became one of the very few opportunities for synchronous exchanges with classmates. Thus, despite the obvious disruption caused by the online transition and the added stress on team members when team tasks were shifted from collective to individual responsibilities, many students reported a positive shift in their team context due to more focused and frequent online team meetings, organized task assignments, and/or new bonding with their teammates.

Not all students perceived positive changes in their team's environment. Some students reported primarily negative impacts from the transition online. Engineering students often reported logistical difficulties with time and scheduling following the transition. For example, one engineering student in C2 was unable to attend the planning meeting where the elementary student and PST decided how they wanted to build their robots. Another engineering student in C3 explained that "it was challenging to find times to meet with my group after the effects of the coronavirus caused us to not be able to go to school to meet." Some engineering students complained that there was not enough time for them to help their PST and elementary students build their robots due to another engineering class that began shortly before the online club session was over. While many students attributed collaboration difficulties to scheduling or the challenge of getting used to communicating with their teams virtually, others did not pinpoint a specific cause but reported a reduction in productivity, communication, and work quality in their team. A few students characterized this as a loss of "connection" as a group. Others experienced a rollercoaster of ups-and-downs with their teams throughout the semester as environmental factors related to COVID-19 and assignment changes were introduced and modifications to team tasks were made.

Some students stopped participating post-transition, and a few withdrew from their courses. Many impacted teammates expressed stress and frustration as they tried to compensate for unresponsive teammates. There were teams where an unresponsive teammate derailed an entire group, but interestingly, there were also positive outcomes. Some students, while initially frustrated, ultimately gained confidence when they successfully assumed responsibilities neglected by their teammates. This experience was conveyed by a PST in C2:

> *"After realizing I was not going to have the engineering partner with me in-person to help with the coding, I was definitely not confident that I would be able to accomplish much with this project. But once I started working on my own, I realized it wasn't so bad and gained confidence after learning to do it on my own."*

Students' choice of technology to facilitate their online interactions also influenced their teamwork. Their choice of tools was often related to their collaboration and lesson delivery mode. C1 and C3 teams were preparing asynchronous lessons, so they may have defaulted to using asynchronous communication tools, such as email and texts, whereas C2 teams were preparing for synchronous Zoom lessons and may have found it convenient to use the same medium for lesson preparation (e.g., several teams reported joining their Zoom link an hour or two in advance of their teaching sessions in order to plan). These choices worked well for C2 teams and for some C1 and C3 teams; however, many C1 teams reported difficulty eliciting responses from teammates through asynchronous communication modes. Research by van Tryona and Bishop [11] found that establishing social connections is challenging in online learning environments where non-verbal communication cues are minimized (e.g., texting platforms, discussion boards). Teams that met synchronously seemed to maintain better social connections than teams that elected to use asynchronous tools. For example, a PST in C2 remarked, "I actually think moving to this [virtual] setting increased my interactions, and the quality of the interactions, with Jack [pseudonym]. We would meet for a full hour before Mikey [pseudonym] (5th grader) got on [line] to plan." Being able to see and hear their teammates may have generated a sense of obligation in these students, which motivated them to be responsive to their teammates' needs. The online Google Sites/Drives used by each team to facilitate communication and file sharing [15] continued to provide support for team interactions throughout the semester. Many teams indicated that it became more beneficial following the transition, especially as a shared repository for their team files.

Applying Bandura's triadic model of reciprocal determinism to analyze the effect of the online transition on students' teamwork, it is apparent that the three factors interacted and influenced one another. In response to the need to adapt their engineering lessons for online delivery (*environmental factor*), some students established new communication protocols (*behavioral factor*), which improved their ability to function as a team and carry out their lessons (*environmental factor*). As a result, students felt more satisfied with the project and their learning (*personal factor*). On the other hand, some team members reduced their participation in the project after the online transition (*behavioral factor*). This created an added burden on their teammates (*environmental factor*). Teammates typically responded by assuming new responsibilities (*behavioral factor*), thereby increasing their workload (*environmental factor*), which resulted in both positive (e.g., enhanced confidence, resilience) and negative (e.g., stress, frustration) personal outcomes (*personal factor*).

6.2. Student Learning from Online Team Experience

The transition to online learning affected what the students believed they learned from the project and from their team interactions specifically. Students noted acquiring professional skills such as leadership, teamwork, and effective team communication strategies as a result of their project experiences, and they acknowledged the project's utility for their future careers. They saw the benefits of cultivating talent and learning how to interact effectively with their team members. For example, a PST in C3 shared that, "due to [a result of leadership changes in her team following the shift to the virtual environment], I think I can now start to take more leader roles in group projects and work well with others without fearing judgment." PSTs and engineering students alike expressed how the project promoted flexibility, resilience, and persistence in professional tasks. C2 students gained valuable experience communicating virtually with parents and teammates, practices they are likely to utilize in their future careers.

Although traditional college-age students in 2020 frequently utilized digital communication tools for personal use, most did not know how to use virtual communication platforms for professional use [34]. Team members with technical prowess were valued and often assumed leadership roles. Thus, many students saw the value in these skills and perceived benefits from learning to use tools to collaborate online. For example, in C2, an engineering student explained:

> *"I think that having to use Zoom to carry out the remainder of this project is beneficial to my preparation for becoming an engineer. Virtual meetings are becoming more standard for many businesses and corporations, and I feel that being able to effectively communicate ideas and information in this manner will become invaluable."*

A few teams successfully completed their lessons as a group of autonomous workers with delegated tasks rather than as a true team that makes decisions collaboratively. Some of these students reported that this arrangement reduced their opportunity to learn from their teammates. This was the case for an engineering student in C1 who described his experience during his focus group:

> *"We had the same primary roles [after the transition]. However, in the [in-person] rehearsal, we were able to build on each other throughout each slide. Doing this conveyed us more as a team and I don't think we captured that same feeling on the online lesson. [. . .] I felt that moving to a virtual lesson affected me negatively. I found that I learned less from moving to online because we didn't get to work together with our teammates as much."*

Many students expressed similar negative experiences as a result of dividing tasks amongst teammates after the online transition. This created a disjointed experience where the benefits of collaboration were diminished. Students who reported less confidence in their skills seemed particularly vulnerable to this effect, whereas more confident students seemed able to absorb defunct partners' roles and move forward. While the interactions of most teams' interactions were not negatively influenced by the online transition, and few teams had negative environments, when there was a negative team dynamic, it was often found to lead to a disappointing learning experience overall for the affected students.

Applying Bandura's SCT lens, it is again apparent how the change in students' team environments both directly and indirectly impacted students' learning regarding teamwork. The team environments also impacted students' satisfaction with their team interactions and, as a result, affected their perceptions of the value of the project as a whole. Figure 3 illustrates how changes in team communication impacted students' environmental, personal, and behavioral factors. A common pathway of influence was for students' perceptions of their team context to prompt them to change their behavior, which then resulted in a personal impact. For example, after realizing that her engineering partner was not going to assist her in the manner originally planned (*environmental factor*), a PST adapted to teaching coding on her own (*behavioral factor*) and gained confidence (*personal factor*) as a result.

Students' personal factors (e.g., self-efficacy, COVID-related anxieties/events, and motivation for the project) also influenced these pathways. For example, a PST with low confidence in engineering (*personal factor*) grew very frustrated (*personal factor*) as she struggled to teach her 5th grader (*behavioral factor*) because her engineering partner was not actively participating (*environmental factor*). Eventually, a faculty member stepped in to assist. In another example, two grade-motivated college students chose to complete their lesson independently (*behavioral factor*) when their unproductive teammates had to unexpectedly drop the course due to COVID-19 implications (*environmental factor*).

Reciprocal interactions between factors were also apparent: when team members changed their behaviors, it changed the team environment. For example, team members who instituted new meeting protocols (*behavioral factor*) reported better team dynamics (*environmental factor*). Other environmental factors, such as feedback from faculty, also influenced team behaviors, such as prompting team members to make additional adaptations to their lessons (*behavioral factor*). As a PST in C3 described, "We changed everything related to feedback. When we got the instructor's feedback, my entire group got on a group call and worked on all of the recommendations until we completed them all."

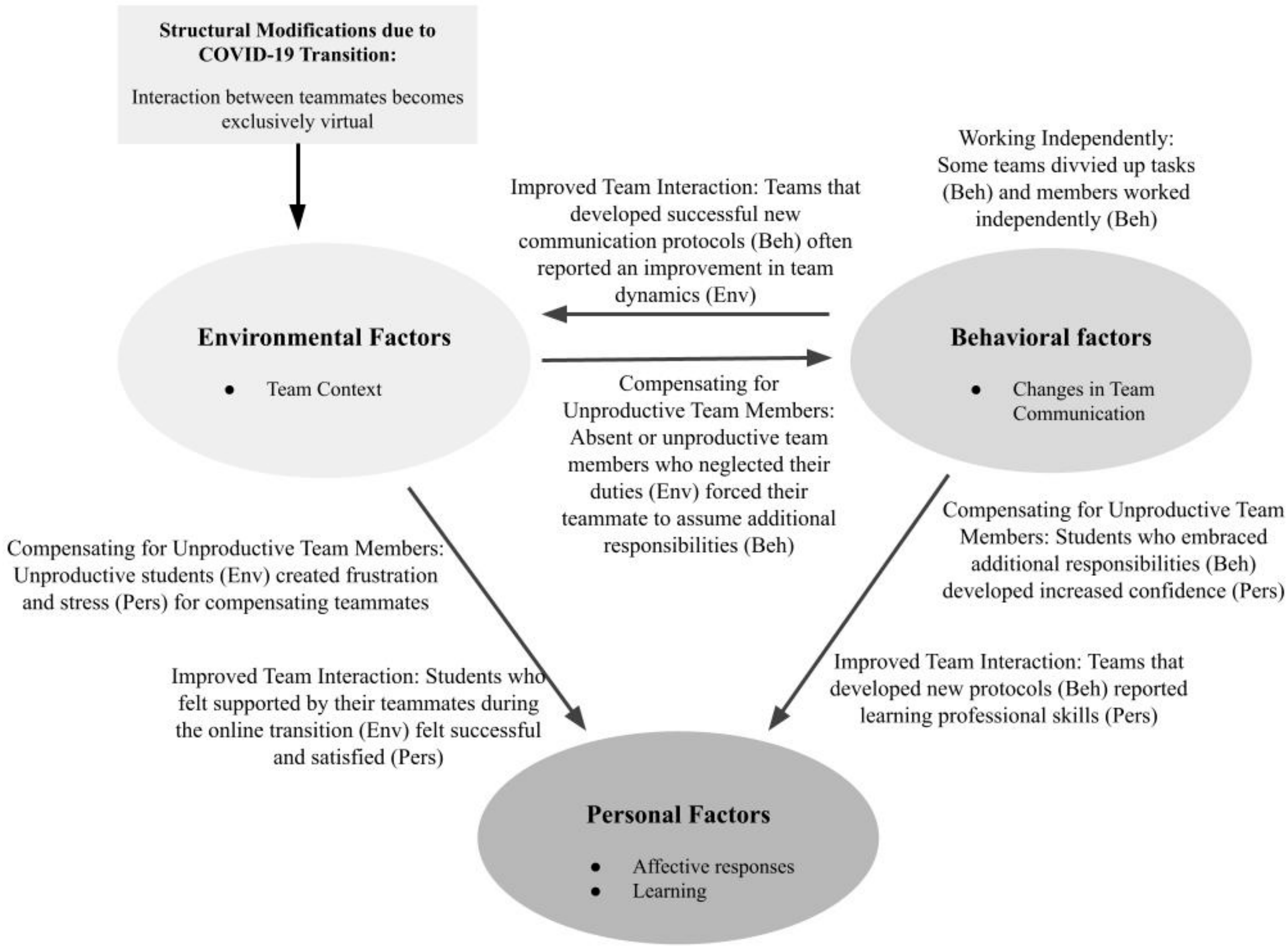

Figure 3. The Influence of Modified Team Interaction (i.e., Moving from Face-to-Face to Virtual Communication) Depicted within Bandura's Triadic Model of Reciprocal Determinism. *Note.* This figure illustrates how environmental (Env), behavioral (Beh) and personal factors (Pers) interact to influence student functioning via examples of commonly reported perceptions. The arrows indicate commonly observed pathways of influence between the factors.

7. Discussion

Bandura's social cognitive theory sheds light on the way the transition to online learning following the onset of the COVID-19 pandemic shaped students' experiences, both directly, by modifying the environment in which they learned and collaborated, and indirectly, through the change in the project goal imposed by the instructors. An examination of the environmental factors of the Spring 2020 semester made it clear that students were responding to a multitude of simultaneous changes: a change in their learning environment, a change in the modality through which they collaborated with peers, and a change in the media they used to deliver instruction. Student experiences were influenced by these environmental factors at both the team and individual levels, and these dynamics were reciprocal so that students both influenced and were influenced by their teams. The students' experiences adapting to these environmental changes can provide insight for all educators, including those involved in teacher and engineer preparation programs, as they consider the best ways to support students engaged in teamwork and develop course assignments beneficial for student learning and professional development. The findings from the current study corroborate and add to the conclusions made by Kilty and Burrows [25] as they examined factors contributing to effective teams in informal settings through integrated STEM partnerships. The concluding sections outline some of the ways in which the current study found that successful partnerships can be established, many of which align closely with prior teamwork and partnership literature [25,35].

While all teams were ultimately successful in that they produced an artifact that met the objectives of their course, some teams reported a more seamless adjustment to their new environmental conditions than others. Several lessons regarding teamwork can be drawn from the experiences of students within their teams. Teams that were able to successfully adapt to their new environmental conditions reported several strategies that helped them succeed: maintaining roles and routines established early in the semester but taking time to meet more frequently if needed; taking time to establish a common understanding of their new task, especially prior to delegating tasks; and using synchronous communication tools that facilitate richer communication. Satisfied teams also found ways to persist despite unresponsive team members.

These findings can help educators plan effective strategies to support teamwork. One such strategy is a practice adopted by the research team several years ago that has proven beneficial for supporting student teamwork even through modifications made mid-pandemic—having students create and sign a team charter. This practice helps team members establish accountability and align expectations regarding the task and create a shared vision of their team plan [36]. Teams in this study also reported being able to establish communication protocols and roles prior to the online transition and being able to maintain these through the online transition. In fully online courses, when students are more likely to feel disconnected [37,38], instructors should help teams develop social structures and communication patterns to accomplish their goals [11].

Another strategy is to promote the use of synchronous communication tools for teams, especially teams that are not able to meet face-to-face. Face-to-face interaction, especially during the early stages of team projects, has been found to be more conducive to establishing trust than meeting virtually [27,28]. Teams in this study had the advantage of meeting in-person during the early weeks of the semester, which may have helped them establish bonds. Undergraduate students who are collaborating virtually and who are unlikely to have significant teamwork experience may be tempted to forgo synchronous meetings and use texting as their primary means of team communication. Instructors would be wise to impose guidelines that require teams to meet synchronously to help establish rapport, especially during the early stages of the projects and for complex and ambiguous tasks. The teams in this study also shared the importance of meeting the needs of their clients, the elementary students. Teams in Collaborations 2 and 3 who were able to meet with their assigned elementary students in either a face-to-face or synchronous format prior to and/or during the school shutdowns shared how valuable those meetings were. This finding aligns with that of Ng [39], where he writes that while students were able to adapt to the rapid transition to online learning, they preferred a hybrid approach where face-to-face interactions allowed them to have "contact and social interactions" [4] (p. 438).

The rapid transition to online teaching and learning was overwhelming to educators and students throughout all grade levels, K-20 [5,6]. Asking elementary teachers to teach the engineering lessons synchronously or distribute the lessons asynchronously for students was perceived as just 'one more thing,' they had to deal with during an already very difficult transition to online learning, and proved to be too great of an additional burden. Accordingly, few elementary students were exposed to the engineering lessons produced. Meanwhile, at the college level, other COVID-related studies found that personal factors for students' learning, such as a lack of self-regulation or independent learning skills, may have made it increasingly difficult for students to be successful in online learning environments [3,5]. Jeffries et al. [3] also acknowledged the mental health concerns for students that may have been "compounded by isolation and lack of connection to instructors and peers" (p. S105).

On the positive side, in the current study in Spring 2020, when stress from COVID-19 was running high, some students found emotional support from their teammates. Prior research has found associations between students' sense of inclusion in a team and their motivation [40,41]. Instructors who want to leverage motivational benefits from team projects may want to consider team building activities that help support team bonding and performance [42,43]. Underproductive team members are a common occurrence in team projects, even outside of semesters affected by COVID-19 [44]. Instructors that require students to prepare for such an eventuality may be less likely to have to deal with fallout later on [45,46]. The COVID-19 pandemic resulted in disruptions that could not have been anticipated. Adequately preparing teams for potential disruptions can help students have successful team experiences regardless of what obstacles appear in their paths.

8. Limitations

As with all studies, there are limitations associated with the current study. First, our study is limited by its particular context. The students' experiences were tied to their participation in an NSF-funded cross-disciplinary service-learning project that involved undergraduate education and engineering students. We cannot assume that college students engaged in team-based projects within a single discipline or across two different disciplines or in the context of a project that was not focused on providing a service to elementary students, would have similar outcomes. The unique and specific context of our project is both an asset and a limitation. It is an asset because it provides a model for how engineering instruction can be delivered online to children in a way that also benefits education and engineering students' professional development, but it is a limitation in that there are many components of this project that could be contributing to the outcomes we witnessed, and it would be nearly impossible to isolate the exact driving forces behind the outcomes we observed. Furthermore, the participants' experiences reflected in this study were collected during a semester that was heavily influenced by COVID. The pandemic created a unique opportunity to study team interactions and draw conclusions and lessons that are meaningful even outside of the COVID-19 context.

Secondly, the complexity of the three factors (i.e., environmental, personal, and behavioral) that comprise Social Cognitive Theory makes it challenging to identify any and all interactions among the factors for any given participant's experience. The social, behavioral, and environmental factors that influenced the students' experiences did so in concert with one another, and although we did our best to identify connections between individual factors, there is no guarantee that a unique combination of influences, rather than a single influence, was not critical in fostering a given outcome. Finally, qualitative analysis provides rich explanations of participants' perceived experiences and is even able to begin identifying causal relationships and explanations in and among the three factors. However, the degree to which these relationships influence or cause one another cannot be answered through the qualitative data examined in this study.

9. Conclusions & Implications

SCT was used as a lens to illuminate the participating education and engineering students' experiences of transitioning to an online environment. The triadic model of reciprocal determinism helped illustrate the relationships among students' environmental, personal, and behavioral factors as they collaborated to develop online engineering lessons for elementary students. Not only can these findings be used to inform other, similar, team-based projects in engineering education that utilize online instruction, but they can also be applied more broadly to help explain the processes by which students' attitudes and beliefs about engineering integration change as a result of environmental modifications.

It has been argued that "once the pandemic is over, [...] new knowledge, skills, technologies, and innovations will remain" [3] (p. S104). The current study examined how the environmental, personal, and behavioral factors associated with rapid changes in university students' teamwork experiences impacted students' knowledge and skills and innovative ways of using technologies to collaborate. Results suggest that the transition to online learning did not significantly disrupt the education and engineering students' ability to collaborate in the development of an elementary-level engineering lesson. Every team rose to the challenge of adapting their lesson for online delivery and produced either a final slideshow that was shared with teachers or delivered a lesson synchronously and directly to elementary school students. The implication of the findings from this study suggests that with the right resources and support, hands-on engineering instruction can be carried out effectively online, even by novices. Additionally, students experienced many challenges while collaborating with their peers to develop online lessons but reported learning new skills and appreciating the opportunity to teach and communicate online, while mostly enjoying their experiences. This project provided these undergraduates with the opportunities to enhance their professional skills, such as communication, collaboration, self-efficacy, and digital skills, many of which were emphasized as areas of needed growth for higher education students in the articles highlighted by O'Dea and Stern [4]. Therefore, while this study is limited to the unique context of pandemic-induced online settings, it sheds light on online engineering education in that future generations can develop their professional skills and effectively teach engineering in online settings.

Future work stemming from this study includes an exploration of the factors that motivated undergraduate students in the project. Thus far, our work is inconclusive regarding the degree to which specific aspects of the project (e.g., interaction with elementary students (clients), commitment to team success, grades, etc.) motivated individual students. Additionally, the project team would like to examine how this interdisciplinary team model influences the development of students' self-efficacy, particularly the pre-service teachers, in teaching engineering to elementary students. Finally, as other scholars have noted (e.g., [3,4]), there is a need for continued examination and evaluation of the best practices in online teaching and learning, particularly in the area of long-term effectiveness.

This interdisciplinary partnership provided pre-service teachers and undergraduate engineering students with the opportunity to develop the teamwork skills they will need in future working environments. It helped students test their ability to work in an online environment, informing them whether they are ready to collaborate effectively remotely, or if they still need more development with that particular skill set. The shift to online learning and teaching in the Ed+gineering project has helped prepare engineering students and pre-service teachers for the increasingly global context of today's professional environments where effective virtual communication is essential.

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