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# Student Engagement in an Online Engineering Afterschool Program During the COVID-19 Pandemic

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## Keywords

engineering education, elementary school, informal learning, student engagement, online learning

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## Introduction

After the COVID-19 pandemic forced schools to close and move instruction online, thousands of students across the USA stopped engaging with school (Burke, 2020; Hamilton et al., 2020; Oberg & Rafique, 2020). The unprecedented and rapid shift to online learning exposed the fact that many districts, schools, and teachers were unprepared and did not have the support they needed to teach students online (Phillips et al., 2021). District and school leaders had to get devices into the hands of students and contend with the reality that many students did not have access to reliable internet or safe and quiet places to study at home (Office for Civil Rights, 2021; Oster et al., 2021). Teachers struggled to recreate their lessons online and, in many cases, to learn to teach online for the first time (Hamilton et al., 2020; Kraft et al., 2021; Pressley & Ha, 2021). Importantly, these struggles were not evenly distributed but disproportionately affected districts and schools serving large proportions of students of color and low-income students (Hamilton et al., 2020; Huck & Zhang, 2021; Kraft et al., 2021). Though districts and schools had the summer of 2020 to create plans and prepare for online learning, many uncertainties remained as the 2020–2021 school year opened.

These challenges raise questions about the consequences of the switch to online learning for student learning and engagement. Several recent studies have investigated how the move to online learning has affected K-12 students, including their level of engagement with their learning. For example, teachers responding to a national survey reported that, in the spring of 2020, their students were disengaged—less than 50% completed online assignments at least 50% of the time (Hamilton et al., 2020). In a separate study, the authors found that levels of student engagement in online school learning were not evenly distributed but rather manifested as an equity problem as it was lower in households with no access to the internet or a reliable device (Domina et al., 2021). However, student engagement increased when teachers provided students with opportunities to interact, encouraged students, provided counseling, or offered socially distanced extracurricular activities (Domina et al., 2021). Student engagement as an outcome matters because it is highly related to student learning (Fredricks et al., 2004) and a valuable outcome on its own (Shulman & Hutchings, 2004). However, school closures affected not only formal learning but also informal learning, such as afterschool programs. For this reason, we focused on an afterschool engineering program for elementary students that transitioned online during the 2020–2021 school year because of the pandemic.

### *Informal STEM Learning*

Among the many informal learning programs available to young kids are those that seek to expose them to science, technology, engineering, and mathematics (STEM) in an informal environment (Allen et al., 2019; Bell et al., 2016; Falk & Storksdieck, 2005; National Research Council, 2009; Sacco et al., 2014). Informal STEM learning can be understood as "the science learning that takes place outside of school" (Staus et al., 2021, p. 1) and can occur afterschool, during the summer, or can be place-based, such as the learning that takes place in museums (Falk & Dierking, 2016). Informal STEM learning capitalizes on learners' intrinsic motivations and allows for exploration and engagement in ways that classroom-based learning cannot or does not (Moreno et al., 2016; National Research Council, 2009; Renninger, 2007). For example, informal STEM programs often offer smaller group sizes, greater instructional flexibility (Dabney et al., 2012) and choice (Falk & Storksdieck, 2005) for instructors, and lower stakes than classrooms (Maltese & Tai, 2010). Participating in informal STEM programs is related to improved STEM knowledge, increased STEM interest (Dabney et al., 2012; Maltese & Tai, 2010), a stronger STEM identity (Allen et al., 2019; Calabrese Barton et al., 2013; Gonsalves et al., 2013; Ryu et al., 2019; Yu et al., 2021), and improved academic self-efficacy (Wilson et al., 2014).

Recent research suggests that informal STEM learning programs enhance student engagement in several ways. For example, a mixed-methods study of middle school students participating in a STEM summer camp in the USA uncovered that the students found the hands-on STEM activities to be engaging (Mohr-Schroeder et al., 2014). Researchers reached a similar conclusion based on a separate mixed-methods study that investigated engagement among fifth-grade students participating in a six-week afterschool engineering program (*Think Like an Astronaut*). The program utilizes hands-on activities and the engineering design process to solve problems and the participating teachers reported that students found the activities engaging (Moreno et al., 2016).

The authors of a third mixed-methods study identified additional informal learning characteristics that support student engagement (Chittum et al., 2017). They examined an afterschool and summer learning for middle school students and found that students' attitudes about their future engagement with STEM (i.e., future coursework and majoring in STEM in college) were positively related to having autonomy and choice within the program, instructional strategies that made the content relevant to students' goals, cultivated students' self-efficacy and interest, and created a caring environment (Chittum et al., 2017).

Finally, two recent quantitative studies of nine summer STEM programs for kids ranging from 10 to 16 years old also uncovered a relationship between choice and instructional strategies and engagement. In the first study, the authors found that whether students choose to participate in the program and their affect (happiness and excitement in the moment) were related to higher levels of engagement, measured as concentration (cognitive) and effort (behavioral) (Beymer et al., 2018). In the second study of the same programs, the authors found that students reported higher levels of engagement when working on activities they described as challenging, relevant, or "having more affordances for learning or developing skills" (Schmidt et al., 2020). These studies point to several promising practices for engaging young learners in informal STEM learning, including the importance of giving participants choice and autonomy and using activities that are both hands-on and relevant to students. However, more research is needed on student engagement in informal STEM learning, particularly in an online context and in the context of the COVID-19 pandemic.

### *The Present Study*

The purpose of this study was to examine the social, emotional, cognitive, and behavioral engagement among fourth- and fifth-grade students participating in an afterschool engineering program that moved online in 2020–2021 because of the COVID-19 pandemic. The following research questions guided the study:

1. How did students' social, emotional, cognitive, and behavioral engagement manifest during participation in an engineering program for fourth- and fifth-grade students that transitioned to an online format during COVID?
2. How did student interest, the instructors, the learning environment, the nature of the activities, and peers in the program affect students' engagement in the program?

We argue that students' social, emotional, cognitive, and behavioral engagement in the online iteration of the afterschool engineering program were inconsistent across the year of implementation. We also contend that student interest, the instructors, the learning environment, and the nature of the activities were most consequential in shaping levels and types of student engagement.

## Student Engagement

We used the concept of school engagement (which we will refer to as *student engagement*) to guide our study. Student engagement refers to students' investment (Marks, 2000; Newmann, 1992; Tinto, 1975) and participation (Kuh et al., 2008) in and effort expended (Pekrun & Linnenbrink-Garcia, 2012; Terenzini et al., 1982) toward their learning in school. Heller and colleagues (2010) contend that engagement is both a process—the doing—and an outcome. Specifically, student engagement manifests in effort, initiative, and curiosity (Fredricks et al., 2004).

Student engagement comprises four dimensions: behavioral, emotional, cognitive (Fredricks et al., 2004), and social engagement (Linnenbrink-Garcia et al., 2011; Rimm-Kaufman et al., 2014; Wang, 2013). Behavioral engagement refers to student behaviors required for success, such as attendance and participation. In an online environment, participation includes keeping one's camera on, raising one's hand (virtually or physically) to contribute to group discussions or answer questions, and completing assigned activities. Emotional engagement refers to the feelings that students experience during the learning process, whether positive or negative. Emotional engagement is not always as easy to observe as behavioral engagement but would include whether students are having fun or enjoying an activity, are frustrated, or bored. Students may express these emotions verbally (e.g., telling others they like a task) or behaviorally (e.g., becoming upset with frustration or focusing on something other than the assigned task when bored) in the moment, or they describe them later when reflecting on an activity or task. Cognitive engagement refers to the effort that students dedicate to learning and completing tasks, including self-regulation. Cognitive engagement may also be difficult to observe. It may manifest as a prolonged focus and concentration on a task, which may be observable or, in the case of online learning where the work may take place off-screen, may emerge after reflection. Finally, social engagement refers to social interactions around the tasks that the students complete as part of their program. Social engagement manifests in the interactions among participants and between participants and instructors that center on informal exchanges and conversations.

## Predictors of Student Engagement

Based on our review of the literature on student engagement in face-to-face and online learning, researchers have identified multiple factors that affect student engagement. As we began our review of the research, we cast a wide net to identify a comprehensive set of factors. For this reason, our search included formal and informal learning settings, online and face-to-face learning, and K-12 education as well as higher education. In this section, we discuss each factor in turn with a focus on engagement in online learning generally and during the pandemic specifically. Where possible, we highlight whether the authors identified a specific link between the factor and one or more dimensions of student engagement. Across the research we reviewed, we found five common predictors of engagement: student interest, teachers, the learning environment and technological affordances, the nature of the activities, and peers.

### *Student Interest*

Students' level of interest in a task influences their level of engagement. Interest refers to the level of enjoyment individuals derive from a task. Interest is an intrinsic motivational belief (Reeve, 2012; Ryan & Deci, 2000, 2020) that has affective (i.e., positive emotions) and cognitive (engagement in tasks related to the object of interest) components (Hidi & Harackiewicz, 2000). Interest develops sequentially over time as an individual interacts with content, such as science

(Renninger, 2007), beginning with a situational interest that, over time, is maintained and emerges into an individual interest (Hidi & Renninger, 2006). Situational interest is associated primarily with affect or enjoyment, while individual interest—the sustained and fully developed phase of interest—is associated with affect and "stored knowledge" about the content or task (Hidi & Renninger, 2006, p. 114). Interest, therefore, is neither fixed nor general: it can increase (or decrease) over time and is content-specific (Renninger, 2000). Importantly, teachers can cultivate interest through their instruction (Lipstein & Renninger, 2006).

Across its four phases, interest is positively related to important learning outcomes. For example, interest can be a powerful motivator for a student to persist (Renninger & Hidi, 2002) and complete a task (Xu, 2008). Researchers find that students who are more interested in a task are more likely to be engaged in the learning or the doing (Ainley, 2012; Ferrer et al., 2022; Fredricks et al., 2004; Milligan et al., 2013), to persist when the task is challenging (Renninger & Hidi, 2002), and to pursue studies and work related to that task in the long run, e.g., a career in science (Maltese & Tai, 2010; Tai et al., 2006).

Interest also is important in online learning. For example, the authors of a mixed-methods study of adult learners enrolled in a massive open online course on instructional design found that a critical predictor of participation was students' interest in the skills being taught (Milligan et al., 2013). In this study, we focus on the students' interest generally given that informal learning gives students the opportunity to develop a new interest—situational interest, sustain an existing situational interest, and more deeply develop an individual interest through challenging but relevant hands-on activities.

### *Teacher Roles*

Teachers play an essential role in facilitating student engagement. Indeed, there is evidence that students themselves define engagement primarily as teachers' enthusiasm for the material and their teaching (Heller et al., 2010) and that teachers can enhance student engagement in engineering education in multiple ways (Chen et al., 2008). Research points to four roles that teachers play in online learning: pedagogical (how they teach), social (how they interact with their students), managerial (how they manage the online classroom), and technical (how they manage the online environment) (Berge, 1995). In the program we describe, undergraduate mentors also acted as teachers (Rangel et al., 2022).

#### *Pedagogical Role*

Teachers can facilitate student engagement through their instruction. Teachers can increase student engagement by designing activities that provide students with autonomy and choice (Reeve, 2006, 2012; Roth et al., 2007; Ryan & Deci, 2009), particularly choices that are aligned with students' interests or goals (Alamri et al., 2020; Assor et al., 2002). For example, the author of a quantitative study of formal, face-to-face learning among middle school students in Korea found that when students perceived that their teachers supported their autonomy, students were more engaged in and proactive about their learning (agentic engagement; Reeve, 2013). Similarly, a recent quantitative study of eighth- and ninth-grade students in Hong Kong who were attending school virtually during the first months of the pandemic found that when teachers facilitated student autonomy in their work, the students had higher levels of behavioral engagement (Chiu, 2021).

Teachers also can enhance student engagement by increasing interaction with and among their students (Ingulfsen et al., 2018; Prince et al., 2020; Van Leeuwen et al., 2013). As an example of the importance of teachers' interactions with students, Chen and colleagues' (2008) review of multiple studies of learner-centered instruction in engineering education found that undergraduate engineering students who interacted more with their instructors were more satisfied with their college education, had greater confidence in their skills, and engaged more in extracurricular activities. A recent quantitative study of the use of in-person and online discussion in engineering education courses to stimulate peer-to-peer interactions enhanced students' cognitive engagement in class (Caratozzolo et al., 2019). The authors of a qualitative analysis of observations of student–teacher interactions in a ninth-grade science class where learning was computer-supported found that students were more engaged in the activities when the teacher provided additional supports and interacted more with the students (Ingulfsen et al., 2018). Similarly, a quantitative study of university students enrolled in a hybrid course found that students were more emotionally engaged—and did better in the course—when the instructor interacted more with the students (Molinillo et al., 2018).

#### *Social Role*

Teachers' social role refers to how they interact with their students. Berge (1995) describes this primarily as the social environment teachers create and their relationships with their students. Online teachers' social role includes managing online interactions, communication with students, helping to resolve conflict, encouraging students, prompting discussion, and providing feedback (Alvarez et al., 2009). In their social role, teachers can attend to students' social and emotional engagement in online learning (Cleveland-Innes & Campbell, 2012; Pentaraki & Burkholder, 2017), making them feel safe and comfortable (Carr, 2014), more efficacious (Chen et al., 2008; Reeve, 2013; Ryan & Deci, 2017, 2020), and like they belong in the classroom (Ascough, 2007; Shea & Bidjerano, 2014). Strong teacher–student relationships encourage student participation (behavioral engagement), student risk-taking (cognitive engagement), a sense of community (Young & Bruce, 2011), and enjoyment (emotional engagement) (Chiu, 2021; Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016; Vollet et al., 2017; Young & Bruce, 2011). Recent research from formal online learning during the first months of the COVID-19 pandemic also points to the importance of teachers' social role. For example, a qualitative study of high school teachers and students in Turkey found that teachers' emotional support helped the students stay engaged in class (Kurt et al., 2022). Similarly, Chiu's (2021) quantitative study of online learning during the pandemic in Hong Kong also found that teachers' connections to students were related to higher levels of cognitive, behavioral, and emotional engagement in the online class.

#### *Managerial Role*

Teachers in their managerial role in online learning environments address procedures, processes, and other administrative or organizational tasks. Management could include responding to students, administering the online classroom, and managing communication and online learning spaces (Alvarez et al., 2009; Martin et al., 2019). Scholars have emphasized the importance of managing the online learning environment to maintain student engagement in learning given that the instructor is not present (Bonk et al., 2018; Carr, 2014; Kurt et al., 2022; Martin et al., 2019; Peltier et al., 2007). For example, a quantitative study of university students' perceptions of online learning highlighted the importance of management—course structure and delivery (Peltier et al., 2007). Likewise, an analysis of interviews with award-winning online instructors in higher education pointed to regular communication with students as an important management task for effective online teaching (Martin et al., 2019).

#### *Technical Role*

In their technical role, teachers manage the hardware and software of the learning environment, including the learning materials, learning platforms (e.g., Zoom, Teams), and learning management systems (Alvarez et al., 2009). When teachers manage the learning environment, they ensure that students can access different classes and small groups, course materials, and activities. For example, Frederick and colleagues (2020) used a mixed-methods design to describe how K-12 special educators at one school moved their intervention system for students with special learning needs and individualized education plans to an online platform to continue to meet students' needs in the early months of COVID. The seemingly simple task of moving the system and plans online meant that students could continue to receive the services and supports outlined in their individualized education plans during the pandemic (Frederick et al., 2020).

### *The Learning Environment and Affordances*

#### *The Learning Environment*

The online environment is the broader context in which students learn online. The learning environment can include the specific applications and websites students use to learn as well as learning management systems. It also can include the physical place where students learn; this could be a student's home or a library in online learning. Technology-rich learning environments can be intrinsically motivating for younger learners accustomed to spending time on devices and online (Arnone et al., 2011), though other scholars argue that the relationship is moderated by students' attitudes towards online learning (Ferrer et al., 2022; Liaw et al., 2008; Wang et al., 2021; Wengrowicz et al., 2018). Online environments also may inhibit engagement. For example, a quantitative study of high school students found that online distractions (e.g., social media) were associated with lower student engagement (Bergdahl et al., 2020). Similarly, a quantitative study of emergency remote learning in spring 2020 found that undergraduate engineering students had trouble engaging in online learning from their homes as they struggled to find quiet places to work and often were pulled into other responsibilities (Snodgrass Rangel & Henderson, 2021).

#### *Affordances*

The technology medium and its affordances also help shape the nature and extent of student engagement (Halverson, 2016; Henrie et al., 2015). Educational technology has affordances or functions that help shape how the technology can and should be used (Koehler & Mishra, 2009; Markus & Robey, 1998). Within undergraduate engineering education, researchers have found that some types of technologies can enhance student engagement, while others may not. For example, the authors of a recent study on the use of simulations in chemical engineering found that the students engaged with the simulation superficially and did not improve their conceptual understanding of the content embedded in the simulation (Streicher et al., 2005). In contrast, several studies of the use of virtual reality and gamification in undergraduate engineering education uncovered positive student assessments of the technologies (Retnanto et al., 2019) as well as increased student cognitive (Coller & Shernoff, 2009) and behavioral and emotional engagement (Mora et al., 2018).

More recent research has explored the relationship between technology and student engagement during the pandemic. For example, participants in a recent quantitative study of emergency remote learning at the postsecondary level identified several affordances as positively related to their engagement in the course, including the announcement feature, which made students aware of course requirements and changes, the group chat feature, which allowed students to interact with each other more informally, the instructor feedback feature, and the screen-sharing feature (Abou-Khalil et al., 2021). In a qualitative study of online learning in spring 2020, the elementary teachers the authors interviewed used affordances in Google Classroom and cell phones to adapt hands-on science experiments to virtual learning, facilitate social–emotional learning, facilitate one-on-one conversations, and answer students' questions (Anderson & Hira, 2020).

### *The Nature of Activities*

The nature of the learning activities themselves can enhance student engagement. Students benefit from having more autonomy in their work (Archambault et al., 2020; Jang et al., 2010; Reeve et al., 2004) and from activities that are relevant, authentic, hands-on, and challenging (Bundick et al., 2014; Chen et al., 2008; Harris et al., 2022; Lamborn et al., 1992; Louwrens & Hartnett, 2015; Martin & Bolliger, 2018). For example, a mixed-methods study of middle school students attending an online school in New Zealand found that students were more cognitively engaged when they perceived the activities as more relevant (Louwrens & Hartnett, 2015). The level of interaction that students experience in online activities also affects their engagement (Dixson, 2010; Kurt et al., 2022; Lazareva, 2018; Martin et al., 2019; Tsai et al., 2021). For instance, the authors of a qualitative study of online student engagement in Uganda found that when students interacted more online, formally and informally, they were more engaged (Lazareva, 2018). Similarly, a recent quantitative study found that those students who were in highly interactive online courses reported higher levels of engagement than students in courses with lower levels of interaction (Tsai et al., 2021). When considering engineering education specifically, researchers argue that active approaches such as problem-based learning, cooperative learning, service learning, and team projects will be more engaging for students (Barkley & Major, 2020; Chen et al., 2008; National Research Council, 2012b; Smith et al., 2005).

### *Peers*

Finally, peers may influence student engagement, though the direction of the relationship depends on the peers. Research on face-to-face learning suggests that peers can influence school engagement. For example, Nguyen and colleagues (2018) found in their quantitative analysis among high school students in a large district in Texas that the nature of the interactions mattered. Specifically, they found that peer-to-peer interactions were not associated with higher behavioral engagement but that peer-to-peer and teacher interactions were (Nguyen et al., 2018). Another quantitative study of elementary students in an urban school found that peer interactions were related to higher behavioral engagement only when peer-to-peer interactions, as measured using social network analysis, were more diverse and distributed across a classroom. In other words, in classrooms where students only interacted with students who had similar levels of behavioral engagement and academic motivation, interactions did not result in higher behavioral engagement over time. In contrast, in those classrooms where students with varied levels of engagement and academic motivation interacted, the students who had low behavioral engagement at the beginning of the study ended up with higher levels of engagement (Cappella et al., 2013).

In online environments, the role of peers in student engagement is less clear. For example, a recent quantitative study of college students during emergency online learning in Lebanon found that students perceived the peer chat function as effective but did not perceive other forms of peer collaboration, such as group work or peer review, to be effective (Abou-Khalil et al., 2021). Similarly, a mixed-methods study of peer interactions among graduate students found when students interacted with each other by using badges, thumbs-ups, and avatars, they were more engaged in the course's online discussion forum (Ding et al., 2017).

### *Summary*

In summary, there are multiple mechanisms that shape the extent to and ways in which students engage in learning, including online informal learning. First, research consistently shows that interest is positively related to engagement in learning, facilitating persistence at and long-term commitment to completing a task. Second, researchers have demonstrated that teachers can enhance students' engagement in four ways: through their instruction and use of collaborative learning, how they socialize with students and encourage students to socialize with each other, and how they manage the learning environment, software, and hardware. Third, the learning environment, including the environment's affordances, also shapes engagement. The online learning environment can be intrinsically motivating for young students but also may present students with distractions from their learning. The affordances available within the technology used can lead to more superficial engagement or to increased engagement across multiple dimensions. Affordances that facilitate conversation and collaboration may be best positioned to improve engagement. Fourth, researchers have found that hands-on, authentic, and open-ended activities are related to increased student engagement. Finally, researchers have found that peers can be a double-edged sword, depressing engagement under some conditions while enhancing it under other conditions. In the next section, we briefly describe how we brought these various elements together in a conceptual model to guide our study.

## Conceptual Model

Drawing on the literature we reviewed, we created a conceptual model to guide our study. The model links the four dimensions of student engagement to five intrinsic and extrinsic influences: student interest, teacher roles, the learning environment, the nature of activities, and peers (see Figure 1). As we approached the study, we expected all the factors to help shape student engagement, though there was decidedly less literature on the effects of peers and engagement in online learning. Moreover, because there is less in the literature about which factors affect which dimensions of engagement, we did not begin this study with more specific hypotheses relating the factors to the four dimensions of engagement.

## Methods

### Design

This qualitative study utilized a case study design (Yin, 2017) to understand student engagement in an online afterschool engineering program for two semesters during the 2020–2021 school year. Case studies call on the researcher to examine one case—"a contemporary phenomenon within its real-life context" (Yin, 2002, p. 13)—to answer "how" and "why" questions about the case (Yin, 2002). The case study can be considered an instrumental case study because we examined one case as an example of more general problems (Creswell & Poth, 2017). As suggested by our research questions, prior to the beginning of the year of online program implementation (the 2020–2021 school year) we were concerned about the extent to which students would engage in the program online. The afterschool engineering program is our unit of analysis.

### Program Description

Though usually a face-to-face afterschool engineering program conducted at three elementary schools with fourth- and fifth-grade Latinx and Black students (Snodgrass Rangel et al., 2021), the program was moved online in fall 2020 through spring 2021 because of the COVID-19 pandemic and the closure of schools to outside groups. The program's mission is to increase awareness of and interest in STEM studies and careers by engaging young Black and Latino students in engineering design through math and science content. The program recruits, pays, and trains undergraduate STEM majors (two-thirds were engineering majors in 2020–2021) to be teachers and mentors.

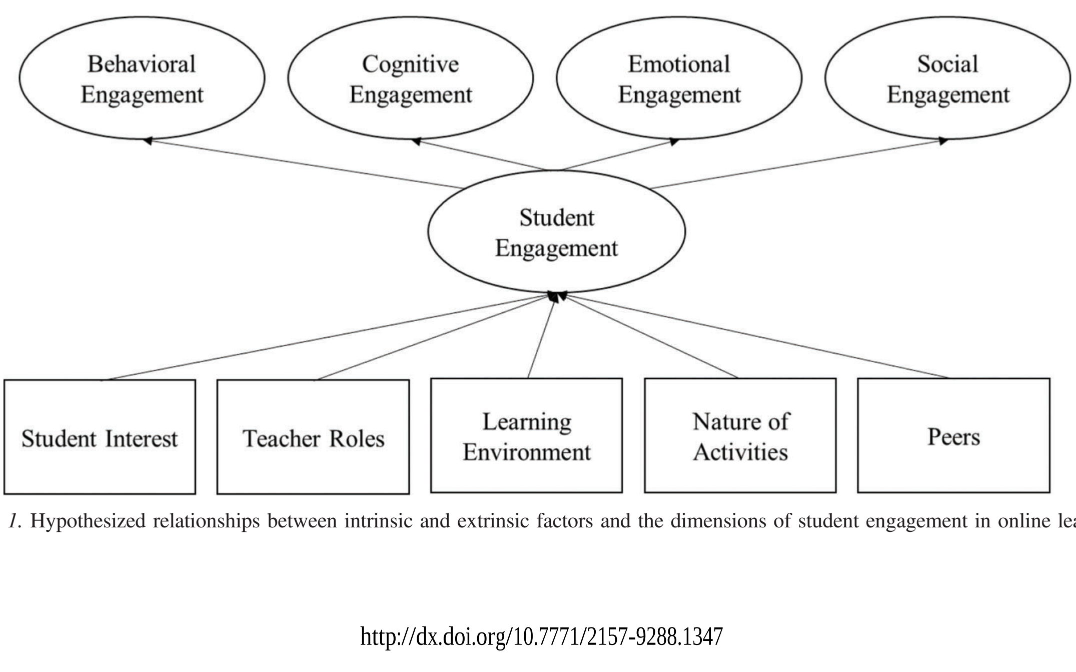


*Figure 1.* Hypothesized relationships between intrinsic and extrinsic factors and the dimensions of student engagement in online learning.

During the 2020–2021 school year, students participated in the afterschool program via Zoom. The program manager created and sent home hands-on kits with most of the materials needed to complete each build; some builds called on students to use objects found in the environment. Students participated three times a week for eight weeks each semester—Tuesday and Thursday afternoons and Saturday mornings—for an hour each meeting and for eight weeks each semester. During the week, approximately half of students joined the program online from their house while the other half (four in both semesters) joined online from their schools. Of the students who joined from school, two used school computers located in a common room where other afterschool activities took place and two joined from a phone while at their school's afterschool program. Because the latter two students shared a phone, they were able to move around. As a result, sometimes they joined from outside the school building (i.e., near a field or playground) while other times they joined from a classroom inside the building.

The program had four key components. On Tuesdays, the session opened with Scientist of the Week (SOW), which featured an underrepresented engineer (i.e., a woman, Latinx, or African American engineer) from a national energy industry company with local operations who gave a short presentation about their work and how they became an engineer. On Thursdays, students spent the first 15 to 20 minutes of the session working on math problems or homework. The latter was new during the pandemic given that many students were attending school virtually and parents may not have been able or available to assist with homework. In the fall semester, volunteers from a local high school math tutoring program assisted the students with math homework or problems. In the spring, the mentors facilitated. Students worked on their hands-on science activities (i.e., builds) throughout the week, spending Tuesday and Thursday learning about the build requirements and creating and iterating on their designs. On Saturdays, they presented their builds to each other, the mentors, and any family members who were present.

Each week, students focused on a different topic and area of engineering (see Table 1). The curriculum is developed in partnership with a teacher preparation program housed at the same university. The preparation program serves secondary math and science pre-service teachers and the supervising faculty help them create and test the lessons, all of which follow the 5E model (i.e., engage, explore, explain, elaborate, and evaluate; Bybee, 2019; Bybee et al., 2006). Some of the activities were open-ended and required students to be creative because there was no one way to reach a solution. Other activities were more structured (i.e., there was a single product that all students were to create, and guidelines or instructions students should follow to create that product) and, therefore, less open-ended; however, the mentors were trained to always encourage student creativity across the activities. The pre-service teachers also meet with the program mentors prior to the first session to walk through the weeks and activities and to complete one together. During these collaborative sessions, the pre-service teachers share pedagogical practices, behavioral management tips, and common student misconceptions.

The program's working hypothesis is that *exposure over time (usually four semesters) to the program's four components is related to an increase in the elementary students' awareness of and interest in STEM studies and careers*. Figure 2 represents this hypothesis as a theory of action.

Though the program manager and mentors made changes to the program after the fall semester (we describe some of these here), the basic routines of daily sessions were similar across both semesters. Students joined the session virtually from either their home or school. When they entered the Zoom room, the mentors greeted them and then led a fun icebreaker to begin the lesson and help the students open up. Based on feedback from the fall interviews with the students, the mentors spent more time on structured socializing in the spring (e.g., asking the students funny questions or questions about the upcoming activity or a holiday). For example, during week three of the fall semester, the mentors ask students what their favorite toys were, and, in a subsequent session, the mentors asked what their favorite Thanksgiving food was.

Table 1
Weekly activities for fall 2020 and spring 2021.

| Week | Fall semester | Nature of activity | Spring semester | Nature of activity |
|---|---|---|---|---|
| 1 | Introduction and survey | NA | Egg drop—material science | S |
| 2 | Reuse and recycle—environmental engineering | S | Solar sails—aerospace engineering | S |
| 3 | Wheelchair ramp—mechanical engineering | S | Miner rescue—structures and obstacles | OE |
| 4 | Ping pong launch—civil engineering | S | Spring break | NA |
| 5 | Field trip week (virtual) | NA | Asteroid lander mission—aerospace engineering | OE |
| 6 | Shoe design—material science | OE | Crash test—mechanical engineering | S |
| 7 | Rube Goldberg machine—industrial engineering | OE | Electrifying the world—electrical engineering | S |
| 8 | Workspace organizer—mechanical engineering | OE | Program celebration | NA |

*Note.* OE, open-ended activity; S, structured activity.

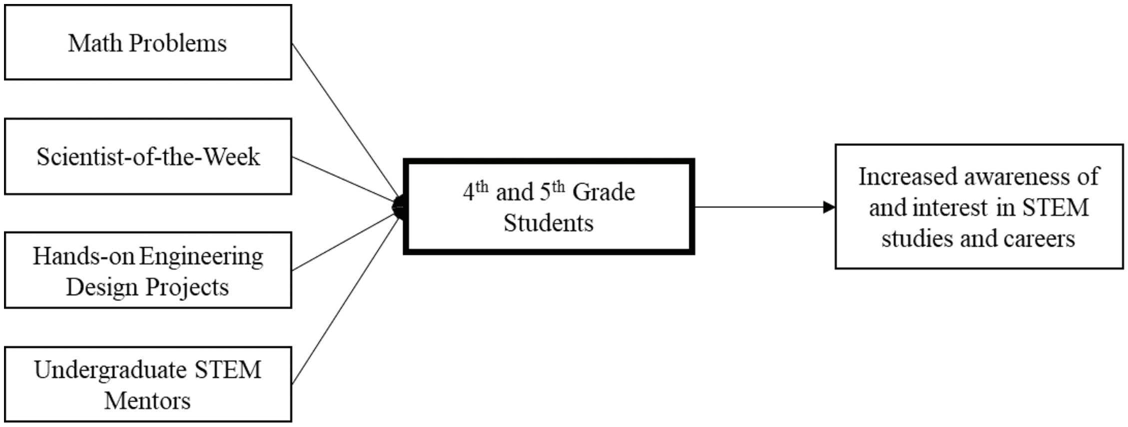


*Figure 2.* Afterschool engineering program theory of action.

When the mentors and students were socializing, the mentors kept Zoom in tile mode so that everyone's picture showed up and the mentors could monitor participation and try to include all students. Then, depending on the day of the week and the focus of the week's lessons, students and mentors had time together to review the materials they could use for the build or to listen to the SOW presentations. During formal presentations, such as SOW, the mentors used Zoom's spotlight feature to focus the students' attention on the guest speaker. In the spring, the mentors shortened the SOW presentations because some students found them boring and hard to follow. After the whole group activity, the students and mentors moved into breakout rooms to work in small groups (usually one mentor with one to three students) on their builds or homework help. In the spring, the mentors utilized the breakout rooms more frequently and for more activities because it increased the interactions they had with the students, which typically comprised helping students with their builds, asking students questions, or meeting privately to discuss an issue. Finally, beginning in the spring, the mentors invited students to choose songs to listen to at the beginning or end of programming.

### *Participants*

Participants included fourth- and fifth-grade students and undergraduate STEM majors. Eight elementary students participated in the program in the fall semester and eight in the spring (only six of those students overlapped between the fall and spring as two students from the fall did not return in the spring, and two new students joined in the spring). Prior to COVID, the program enrolled between 10 and 20 students at each school, each semester. Enrollment during COVID did not exceed 10 students in either semester across both participating schools. We invited all students in the program to participate in the study and all the students consented and participated in the research activities. Table 2 describes the students who participated in the study, presents a pseudonym for each student, and indicates the semester(s) in which they participated in the program.

The program manager recruits students from the elementary schools that have agreed to host the afterschool program. In the 2020–2021 school year, the program manager coordinated with the principals from the two schools that had agreed to host the program online that year to send flyers and applications home with all fourth- and fifth-grade students. The application asks students about themselves (i.e., basic demographic questions) and asks them to write a short paragraph explaining why they want to be in the program. Parents must sign a consent to participate form and then send the application back to the school. Historically, the program has accepted all students who have completed the application.

The elementary students who participated in 2020–2021 were from two different schools: a traditional public school and a university-affiliated charter school. Though the program had permission to be in three schools, students from only two of the schools enrolled in the program. Though we do not know for sure, we speculate that students at the third school declined to participate because of the challenges they likely faced that year: e.g., a lack of access to reliable internet and increased stress at home if family members contracted COVID or lost jobs during the economic slowdown. Indeed, the school from which students did not participate (but had participated in the program for the previous three years) is in one of the most economically distressed communities in the city, while the other two schools are located in a working-class community within the city or draw from across the city.

The traditional elementary school whose students did participate is located in the heart of the city in a historically working class, Mexican American community. Over 95% of the students attending the school are eligible for the federal free or reduced lunch program and are Latinx. The school offers a successful dual language program and has a very active parent–teacher organization. The university-affiliated charter school, which closed at the end of the 2020–2021 school year

Table 2.
Student pseudonyms, gender, and race or ethnicity.

| Student name | Gender | Ethnicity/race | Semester |
|---|---|---|---|
| Akira | Male | Asian American and Black | Fall 2020 |
| Grace | Female | Asian American | Fall 2020 and spring 2021 |
| Jose | Male | Latino | F20 and S21 |
| Marcus | Male | Black | F20 and S21 |
| Sarah | Female | White | F20 |
| Henry | Male | White | F20 and S21 |
| Hector | Male | Latino | F20 and S21 |
| Luis | Male | Latino | F20 and S21 |
| Alejandra | Female | Latina | S21 |
| Lorena | Female | Latina | S21 |

Table 3.
Mentor pseudonyms, gender, and race or ethnicity.

| Mentor name | Gender | Ethnicity/race | Semester |
|---|---|---|---|
| Abaeze | Male | Black | Fall 2020 and spring 2021 |
| Roberto | Male | Latino | F20 and S21 |
| Hai | Female | Asian American | F20 and S21 |
| Raquel | Female | Latina | F20 |
| Alexander | Male | White | F20 and S21 |
| Isaac | Male | South Asian American | F20 and S21 |

as a result of pandemic-related budget cuts, was a very small community (140 students) that drew families and students from across the city. Many students had parents who worked at the affiliated university as faculty or staff, and so some, but not all, students had high levels of exposure to STEM outside of the school setting. Just under half of the students at the charter school were eligible for the federal free and reduced lunch program, 34% were African American, 43% were Latinx, and 14% were White.

There also were six undergraduate STEM students who worked for the program and participated in the study. The mentors are recruited from across the university where the afterschool program is housed through the distribution of a flyer via departmental listservs, engineering courses, campus-based professional organizations such as the National Society of Black Engineers, and college-wide email blasts. Interested STEM majors must complete an application and are then invited for an interview with the program manager. The program pays mentors a stipend and provides two days of training each semester and holds staff meetings every week. The two-day training covers a range of topics including the program's history, program objectives and expectations, the purpose of mentoring, classroom management techniques, daily procedures, and culturally responsive mentoring. The training mixes direct instruction (e.g., describing procedures) with group discussion (e.g., what experience has had the most significant impact on your life?). During the weekly meetings, the mentors meet with the program manager to discuss ongoing challenges, potential solutions, and future sessions. During the 2020–2021 school year, these meetings were held via Zoom, though normally they are held face-to-face. Table 3 describes the mentors and indicates in which semester(s) they participated.

### *Data Collection*

All data presented here are qualitative in nature (including student engagement) and derive from end-of-semester interviews with the students and mentors and observations of the program sessions. For all the interviews, we invited participants to join a Zoom call at a time convenient to them (and, in the case of the young students, their parents). We interviewed the elementary students after the program ended in the fall and spring semesters, and we interviewed the mentors in the two weeks following the end of the program in both semesters. Two members of the team conducted the interviews, but only one led and participated in each (i.e., no interviews had more than one researcher present). Participants joined the Zoom calls from their homes or dormitories (undergraduate mentors). The mentor interviews lasted 45–60 minutes and were semi-structured (see Appendix A for the interview protocol). The student interviews lasted between 20 and 35 minutes and were semi-structured (see Appendix B for the interview protocol). All interviews were audio-recorded and transcribed professionally; transcripts will be maintained for three years, per the terms of the IRB approval. In addition, we formally observed two weeks (six sessions) of the program each semester for a total of 12 sessions. Observations lasted 60 minutes and because the observations took place on Zoom, we recorded the sessions, including many breakout rooms. One of the authors also took detailed field notes during the observations that we did not video record.

### *Data Analysis*

Two of the authors analyzed the interview and observation data using an iterative process and triangulation. In this section, we explain our process in greater detail.

#### *Analysis of Interview Data*

We began our data analysis by engaging in an iterative process in which we read and coded the transcripts twice (Saldaña, 2015). In the first round of coding, two members of the team reviewed and discussed the *a priori* codes we identified from prior research (Wang et al., 2017) (see Appendix A for the codes) and then applied them to the transcripts in the qualitative software package Dedoose (version 9.0.17). The *a priori* codes derived from our literature review on student engagement (e.g., behavioral engagement). Then, we read through the transcripts a second time to identify emergent codes, which related to specific program components (e.g., SOW), barriers to engagement (e.g., distractions), and the mentors' strategies to re-engage the students (i.e., actions the mentors took to keep the students focused and participating), among others. We identified the factors that affected student engagement primarily using our emergent codes. Once we had a list of emergent codes, we met to discuss and define each and to break down the emerging codes further, as necessary (e.g., we identified that there were barriers to engagement and further broke down those barriers into the learning environment, the programming, and external distractions). We returned to the transcripts for a second round of coding using the list of emergent codes.

During this second round of coding, we used Dedoose's training center function with three transcripts (one mentor and one student transcript at the beginning of the second round and a second mentor transcript in the middle) to calibrate our understanding and application of all the codes (*a priori* and emerging) and to establish inter-rater reliability (Guest et al., 2012). The kappa scores were low, ranging from 0.08 to 0.46 across the three transcripts (Landis & Koch, 1977). For this reason, the two authors reviewed the results for each transcript together in the training center and discussed each excerpt and all points of disagreement (e.g., only one of the two authors coded an excerpt from a mentor about experiencing burnout and cognitive overload as cognitive disengagement). We adjusted our coding to reach 100% agreement across the three transcripts (e.g., we agreed to remove the cognitive disengagement code from the mentor's excerpts because the study's purpose was the investigate the elementary students'—and not the mentors'—engagement).

Once we completed the second round of coding, we downloaded two spreadsheets (one for fall 2020 and a second for spring 2021) with the excerpts and assigned codes from Dedoose. Though we read and analyzed the transcripts from the fall and spring transcripts together, we saved the fall and spring excerpts in different files. We did this because the mentors made several changes to how they implemented the program between the fall and spring, and we wanted to be able to identify any related changes in student engagement. We worked from those spreadsheets to identify how the students described their engagement in the program (e.g., it was fun or at times boring) and how the mentors described students' engagement (e.g., students were excited by activities or were distracted by their surroundings) to capture the type of engagement. It is important to note that as we analyzed the data, it became clear that some examples of engagement could be double coded as more than one dimension of engagement as they were closely related. For example, having fun in the program (emotional engagement) was highly related to students enjoying spending time with the mentors (social engagement). When we encountered such overlapping moments of engagement, we returned to Wang and colleagues' (2017) operationalization of each dimension of engagement to decide which dimension was the best fit for what was described or observed.

Then, we identified which, if any, mechanism was connected to the manifestation of engagement. In some cases, this was easier to do. Sometimes the participants themselves made the connection for us, for example when a student told us they were bored sometimes (emotional disengagement) because they already knew a lot of the content because they really liked math (interest), or when students told us that they struggled with a build (cognitive engagement) because of the open-ended nature of the build and the many materials available to them (nature of the activity). In other cases, we relied on the mentors' accounts of the steps they took to redirect and re-engage students (e.g., a mentor using a breakout room (an affordance in the learning environment) to help a student with a build (cognitive engagement) or to check-in with a student (social or emotional engagement)). In both cases, we also were able to draw on our observations to find evidence for the connections between engagement and mechanisms that participants discussed.

### *Analysis of Observation Data*

We utilized the live and recorded observations to triangulate our interview data by seeking examples of connections between student engagement and the mechanisms in practice. We analyzed observation data by reviewing the field notes and the recordings, using the *a priori* and emergent codes used to analyze the interviews to identify moments, interactions, activities, and dialogues that helped identify manifestations of engagement and the mechanisms facilitating engagement. We captured who was participating, the activity, the dialogue, and the code in a spreadsheet. For example, as we watched the video recordings, we took notes on who was speaking (i.e., a mentor or a student), what the speaker(s) was/were saying (in many cases, we wrote down parts of conversations verbatim in the spreadsheet), and what other visible participants were doing (e.g., watching the screen, playing video games, spinning in their chair). Once we had recorded these details, we would apply relevant codes. For example, a moment when a student raised their hand—virtually or physically—would be coded as behavioral engagement. Similarly, we coded the question or conversation that prompted the raised hand as a mechanism facilitating engagement (in this case, a proactive mentor strategy to encourage engagement; we disaggregated the mentors' strategies according to the four teacher roles that Berge (1995) described).

It is important to note that while working on Zoom in some ways facilitated our observations, in other ways it also limited our observations. For example, we relied on students to keep their cameras on to be able to see them, but some students turned their cameras off on some days. The use of Zoom's spotlighting feature, which enlarges the video stream of one participant and shrinks the other streams, also meant that sometimes we had a hard time seeing all students. This was a problem, for example, during the SOW, when the engineers often also shared their screens, which made it even harder to see the students. We only were able to observe what was happening on-screen and with microphones turned on. If mics were turned off, we could not hear exchanges and if something was taking place off-screen, we could not observe it. Finally, when the mentors worked with students in the breakout rooms, they were not consistent about hitting the record button and so while were able to observe many breakout room sessions, we were not always able to record them. In those cases, we had to rely on our field notes.

### *Trustworthiness*

Throughout the study, we sought to enhance trustworthiness in three ways: triangulation, regular researcher meetings during the coding process, and prolonged engagement in the field (Creswell & Miller, 2000). Triangulation is achieved when researchers search for and leverage agreement across more than one data source (Creswell & Miller, 2000; Denzin, 1978). In the present study, we triangulated across methods (interviews and observations). For example, in our interviews we asked students whether they ever felt distracted during the session. We were able to compare students' responses (which were quite honest) with the recorded observations to search for examples of boredom (e.g., playing a video game off-screen or spinning in a chair) versus engagement (e.g., raising a hand, participating in discussions). We facilitated triangulation by asking students and mentors to describe specific builds and sessions, which allowed us to view those recordings to search for evidence for the engagement or mechanisms described in the interviews. We sought to enhance conformability by meeting regularly throughout data collection to share and reflect on the data. We reflected in two ways: informally, through bi-weekly meetings during which we discussed our findings, and formally, using Dedoose's training center to identify points of agreement versus disagreement. When we found points of disagreement, we returned to the codes to clarify meaning and then updated our coding accordingly. Finally, we sought to enhance credibility by engaging with the afterschool program for a prolonged time (Fetterman, 2019). Specifically, the first, second, and fourth authors have worked with the program since 2017 and 2013, respectively, and the third author observed every online session during the 2020–2021 school year.

### *Position Statement*

The identities and positions of the researchers are an important consideration with any research. Researchers must examine their own identities, engage in reflection, and consider the context that the researcher and participants inhabit (Milner, 2007). One's positionality serves as a lens through which one sees and interprets the world. Though this is not a thorough reflection on our identities and positionalities, we do want to share about ourselves and our relationship to the afterschool program. The first author is a White woman and an education professor. As a White woman and an outsider to the practice of engineering, she has worked closely with her team to identify and mitigate her biases. The second author is a Black male, an engineering professor, and the cofounder of the program. He helped start the program in 2013 in large part because he benefited from Black mentors in engineering as a student. The third author is a female Hispanic graduate student within a higher education program. As a newcomer to engineering and afterschool programing, this opportunity has helped her expand her knowledge in research focused on STEM outcomes and mentoring. The fourth author is a Black man, a cofounder of the program, and the program manager. As with the second author, he benefitted from strong mentors and sought to provide those experiences for young Black and Brown students interested in engineering. He manages the implementation of the program and supervises the program mentors. Though the description of our team is brief, it demonstrates that our team is diverse, which is both a weakness and a strength. It means that we have multiple perspectives and experiences to draw from while conducting the research. However, it also means there is a mix of insiders and outsiders, which can affect everything from the program design to the interpretation of the findings. We have worked as a team to attend to our different experiences and positions continuously but recognize that this work is ongoing and imperfect.

## Findings

In this section, we present our findings, which we have organized by research question. We begin with how student engagement presented and then we explain how the external factors—student interest, teacher roles, the learning environment and affordances, and the nature of the activities—influenced students' engagement and disengagement.

### *Manifestations of Student Engagement*

In this section, we answer our first research question, *how did students' social, emotional, cognitive, and behavioral engagement manifest during participation in an engineering program for fourth- and fifth-grade students that transitioned to an online format during COVID?* We begin by summarizing how often students (Figure 3) reported and the mentors (Figure 4) described the students being engaged and disengaged across fall and spring interviews and the average times each form of engagement was mentioned per interview. As we depict in Figure 3, students were most likely to report being emotionally engaged and least likely to report being behaviorally engaged. Students described being more likely to be cognitively than social engaged during the program.

Similarly, the mentors described students as most likely to be emotionally engaged and behaviorally *dis*engaged. In contrast to students' responses, mentors described students' social engagement more frequently than their cognitive engagement.

In the remainder of this section, we share representative responses from students and mentors and describe moments and interactions from our observations that characterize how the four types of engagement (behavioral, emotional, cognitive, and social) manifested in fall and spring 2020. We also describe behavioral disengagement because it was so prominent relative to the other forms of disengagement, particularly according to the mentors.

### *Behavioral Engagement*

Student behavioral engagement manifested as their participation in discussions and builds. Students and mentors described students' behavioral engagement much less than the other forms of engagement (mentioned 10 times across interviews with mentors and students). In our fall and spring interviews with the students, we did not code any instances of

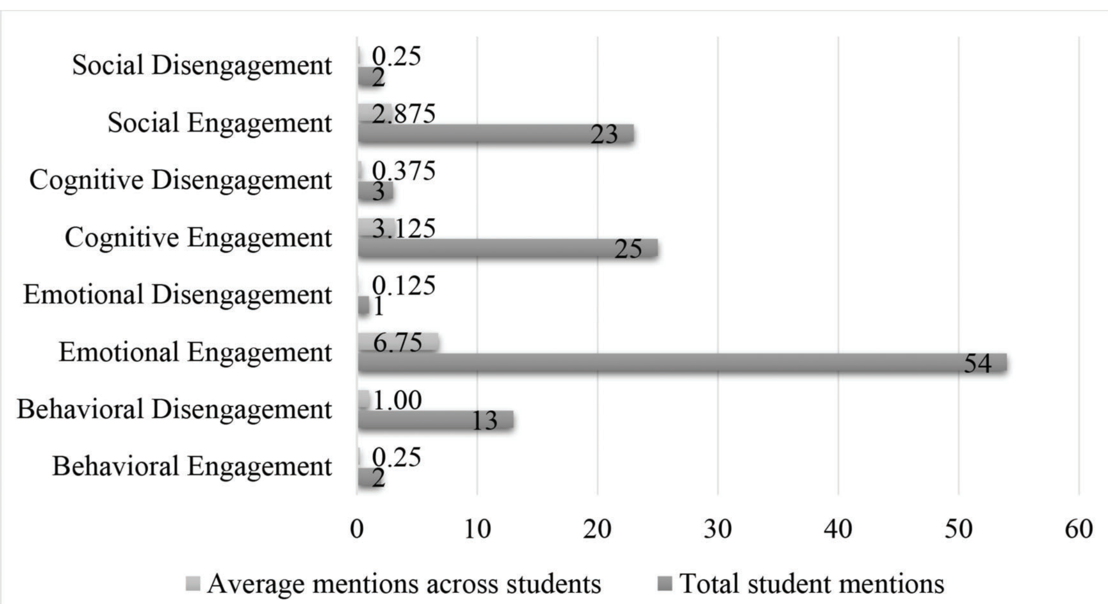


*Figure 3.* Manifestations of engagement by student responses.

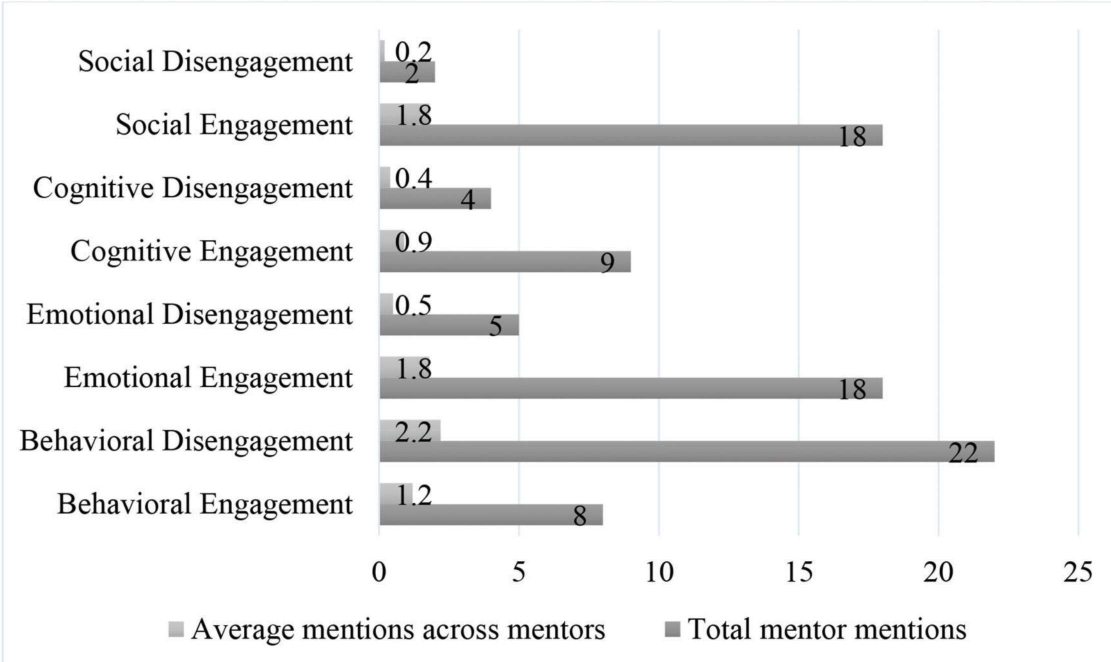


*Figure 4.* Manifestations of engagement by mentor responses.

behavioral engagement and so we had to rely on our interviews with the mentors and our own observations of the sessions to identify examples of behavioral engagement. The mentors described behavioral engagement primarily as the students' participation in discussions and their completion of the builds. For example, in fall 2020, Alexander described for us how completion of the builds varied from week to week, depending on the focus. He explained that the week they created a bouncy ball was "the week we had the highest participation and kids actually made the projects and did them." Abaeze described behavioral engagement in terms of their participation during the sessions, telling us, "I guess the level of interaction participation, you could definitely see on their kids. It's kind of like you'll have those few students that didn't do anything, and you'll have those few students that did something." The mentors also noted that participation in the sessions and builds increased in the spring.

Drawing on our observations, we characterize students' behavioral engagement similar to how the mentors do, in terms of their participation during the sessions and their completion of the builds. We observed behavioral engagement as students taking steps to participate, for example, students eagerly unmuting themselves to share a story during the icebreakers. One instance where we observed this was during the recycle week when the mentors asked students to share their favorite toy. Several students ran off-camera to go get the toys and excitedly shared their reasoning behind why it was their favorite toy. Additionally, we observed that in the spring semester students shared more personal details with the mentors and they would ask the mentors personal questions. For example, they would ask about the mentors' favorite places to find different ethnic foods, their hobbies, and the builds. In the spring, we also observed more student-initiated social interactions. With this increased participation, the mentors eventually let the students decide the icebreaker questions and even added an exit song to the program. Students would ask questions such as, "what's your favorite anime?" or "where is your favorite place to eat?"

More so than behavioral engagement, we heard about how student *dis*engagement manifested during the sessions. In our interviews, two-thirds of students admitted that they had been behaviorally disengaged at least once during the fall or spring semesters ($n$ = 11 mentions, $M$ = 1.6 mentions per interview). They described this as being bored, not paying attention, or being distracted, manifestations that were consistent in both semesters. For example, Grace described how she sometimes had a hard time paying attention during math problems because she was bored:

> It felt like even when they're doing the presentation, it was easy to let things slip onto my mind other than what we're doing because a lot of the concepts that we're learning I already knew quite a bit about that concept already, especially the math.

Sarah, who participated only in the fall and joined the sessions from home, described being distracted by her brother in the background: "I would want to play with him but I also want to wait until they tell us what we have to build."

The mentors' description of students' behavioral disengagement was similar: being bored or distracted. For example, Isaac described how the students grew bored during the SOW, saying, "They're just lost, dude. You look at their cameras, they're zoning off. I don't know what they're looking at." Alexander shared that the students sometimes became distracted: "I know one or two of them had a habit of playing video games during class or one of them in particular." At least two students admitted to playing video games occasionally during sessions and we were able to observe at least one student, Henry, staring at a different screen with a game controller in his hands. In the spring, the mentors described the students as more engaged, but noted that three students who joined the session from the common room in their school were more likely to become distracted. Roberto shared that in the spring semester, the mentors "had an issue with seating at one point. I got Jose telling me like, 'They're [the other two students] being mean to me.'"

*Emotional Engagement*

The students and mentors described emotional engagement as their excitement about and enjoyment of the program. Nine of 10 students explained how they were emotionally engaged in the program across both semesters ($n = 54$ mentions, $M = 6.75$ mentions per student interview), and five of the six mentors described how the students emotionally engaged during the two semesters ($n = 18$ mentions, $M = 1.8$ mentions per mentor interview). In the fall, emotional engagement manifested primarily as students having fun and being happy or excited. For example, Marcus told us in fall 2020 that he felt excited on the days the program met because he enjoyed the builds: "I always felt excited." Henry echoed this sentiment: "I was excited for STEM days because I always wanted to know what's the new cool toys or things I would have to build." The mentors described students' emotional engagement in the fall in similar terms. For instance, Hai told us,

> The way they present the toys, they were very excited about it. They were just like, "Oh, my gosh. I did this." When we praise them, that was something like they felt very proud of themselves for doing such a thing. You can just see the joy through the way they explain, how they come up with the idea, and how they were able to make that materials to a toy that they want.

In the spring, emotional engagement included excitement and expanded to include students' relief from school and the trust they were developing with the mentors. Alejandra, who joined in spring 2021, echoed the excitement expressed by students in fall 2020: "It was fun, because I can present it, because it's like—like [the mentors] help you do some more stuff." Lorena, who also joined in spring 2021, expressed a somewhat different sentiment. She told us that she felt excited on the days the program met because, "I feel like this was our escape from our responsibilities for one hour… [the program] just gives me that one hour to be myself, talk and be with my mentors." Lorena also described the connection she developed with one mentor, who comforted her after a family member died. She recounted how Hai had met with her in a breakout room when she was feeling sad, and how the gesture made her trust and feel connected to Hai. In our interview with Hai, she described this same interaction as the moment when she, too, felt more connected to the program and the students.

*Cognitive Engagement*

Students' cognitive engagement manifested as creativity and persistence. For example, the students described for us how they used the materials available to them, including materials from around their house, to complete their builds. Grace told us that her favorite build was one where she was able to be creative. She explained that she enjoyed the project because, "It was fun. It was like a free throw project. You could just do whatever you thought might work." The mentors also described students' cognitive engagement as being creative. For example, Abaeze described students' engagement in two of the fall 2020 builds in this way:

> I felt like, out of all of those, those were two that just made them think, that made them get up and consult with their parents on what they thought would be great, and it allowed them to use their critical thinking skills to come up with something dope, and you had students that weren't even really saying much that was getting into the vibe of it.

Students also described their cognitive engagement as persisting through the hard work often involved to understand a concept or complete a build. For example, Alejandra described how she worked through the math problems of the day, many of which were challenging for her: "Even though it's challenging, you can still do it. I once couldn't even do subtracting, but with like 1000 or something like that, and now I can." Similarly, Abaeze described how the students worked hard on one of the builds, the Chilean miner rescue, despite the challenge of creating a crank and the multiple constraints built into the project.

*Social Engagement*

Students described their social engagement primarily in terms of their interactions with the mentors. Social engagement was the second most commonly mentioned form of engagement across all our interviews (mentioned 41 times across all interviews): social engagement was mentioned at least once in every student interview in both semesters (mean = 2.85 times, maximum = 7) and at least once in all but one mentor interview from both semesters (mean = 1.8, maximum = 6). Moreover, we were able to observe many instances of social engagement each session as the program manager together with the mentors built in time every session for the students and mentors to socialize—to share stories, tell jokes, and answer silly questions. The purpose of these non-engineering-focused opportunities to share was to build community and to mitigate the negative effects students might have been experiencing because of social isolation throughout the pandemic. In the first semester, these moments were not as consistent but, because they were successful, the program manager and mentors decided to schedule them for all online sessions beginning in spring 2021.

Social engagement among the students manifested as informal and usually positive interactions among the students and between the students and the mentors. The students primarily described how they socialized with the mentors. For example, in fall 2020 Henry described how he liked hearing about the mentors' interests. He recounted, "one of [the mentors] said they like drawing, and as a kid, I also liked drawing. One of them also said they like cool cars. I like cool cars, but my brother likes them more. I like cool cars." In the spring, more students mentioned social engagement than in fall (fall $n = 2$ students, spring $n = 4$ students), which reflected the programmatic change increasing time to socialize. As in the fall, students primarily described their social engagement in terms of their interactions with and what they learned about the mentors. For example, in spring 2021 Lorena recounted how she shared interests with two of the mentors—pie and anime. Hector also described his social engagement during the program in terms of interacting with the mentors: "We go to talk to them, like share more about our interests. It was cool." These social moments, however brief, helped the students feel connected to the mentors and the program.

The mentors also described the students' social engagement as informal and fun interactions with the mentors. For example, in fall 2020, Alexander described how the mentors shared their own interests or made jokes with the students to get the students to open up and participate more. He explained that during these informal times, students could talk about "whatever they want to talk about," adding that "cracking a few jokes and not being formal is very important." Roberto stressed that, "just having that personal connection…really helped."

The mentors' description of students' social engagement in spring 2021 reflected the increased time for informal interactions and revealed some student-to-student social engagement. For instance, Abaeze described how Jose and Lorena, who attended different schools and did not know each other outside the program, were both interested in anime, which they learned through the informal socialization time. He recounted how the students "literally just started talking and giggling, having fun and stuff like that." Alexander described how the decision to let students choose music for the opening and closing of the program each day also led to increased social interactions between the mentors and the students: "just as soon as I started listening to the song and then she started singing too, I was jamming. That was a really cool interaction."

*Mechanisms Affecting Student Engagement*

In this section, we answer our second question, *how did student interest, the instructors, the learning environment, the nature of the activities, and peers in the program affect students' engagement in the program?* We explain how four of the five external factors influenced how students engaged with the online engineering program.

*Student Interest*

Most students identified their personal interest in the program and activities as reasons for their engagement. For example, when Grace told us she was excited on the days the program met, she explained that it was because, "…in general [I] like learning about the topics that we're doing each week…In general, I already had background knowledge and knew what I did or really liked doing or didn't really like." Similarly, Henry told us that he liked learning new things and sharing his work. He recounted, "Well, that you get to learn something new on Tuesday. On Thursday, [the mentors] can help you with some homework, if you have any. Saturday, you can present your awesome inventions." Finally, Lorena told us that she already liked to build things at her house:

> I literally wanted to build something. So, I got some pieces of wood, cut out the parts I need, like the little handles, and it's not batteries. I didn't make little batteries because I don't know anything with wires and anything, and then I printed out some stickers—well, my mom did—I printed out some stickers, and then painted it, put it all together, and then I made my moving clock.

Student interest resulted in emotional and behavioral engagement in the program. Specifically, students described feeling excited because they enjoyed the activities and were eager to find out what they would build. For example, Alejandra shared the following:

> Interviewer: What do you get excited about?
> Alejandra: About that you can learn new things.

We also observed students in how they participated in the builds. For instance, we observed several who were so excited for different builds they would run off-camera to get the materials. In one session, Sarah went off-camera and then came back with a giant cardboard box that was bigger than she was, a pair of scissors, and a couple of other items. She started to explain how she was going to do her build and then started working on camera. Students also told us that they sometimes felt nervous ahead of the Saturday presentations of their projects to the rest of the group. For example, we had the following exchange with Alejandra about how presenting her work and answering the other students' and mentors' questions made her feel:

> The first day, it was kind of awesome. Well, I was really, really scared. I was showing them, and then the questions that they asked was, "Is it on top of the table? Can it be lifted up?" And "What do you think you would have improved with your…?" you know.

In contrast, we heard from one student that her personal interest in STEM sometimes meant she was bored in the sessions. Grace, who described enjoying learning about engineering and having prior experience with builds and competitions, also conceded that she sometimes found parts of the program boring because she already knew the content or, in some cases, had done similar activities. In this way, her high level of interest in STEM generally sometimes meant that she was behaviorally disengaged in the program.

*Mentors' Roles as Teachers*

Data from the interviews and observations suggest that the mentors played a central role shaping—enhancing—student engagement. In this section, we review evidence linking the mentors' teaching roles (pedagogical, social, and managerial roles) to different forms of engagement.

*Pedagogical Role.* We heard about and observed the mentors' pedagogical roles. The mentors used three instructional strategies to encourage behavioral, emotional, and cognitive engagement: questioning, demonstrations, and feedback and encouragement.

*Questioning.* The mentors described questioning as a common strategy to encourage participation and elicit students' thinking. For instance, Hai told us how she used questioning to engage the students more: "I know a lot of students do not like this, but we pick them, trying to let them talk, or asking literacy questions. Those would be the way for us to make them more engaged in the program." Abaeze also shared how he would probe the students' responses for greater understanding: "I did ask a lot of questions in terms of like, 'Why did you do that?' and it was a lot of like, 'I don't know,' but those are the types of questions that I always try to, you know, engage with them on." We heard from four students who said the questioning made them both nervous (emotional engagement)—they were worried about being put on the spot—and work harder (cognitive engagement)—in case they got put on the spot with a question. Isaac added that asking follow-up questions demonstrated that the mentors listened to and were interested in the students, which cultivated their emotional engagement. He told us, "Listening to the kid and then following up on what they say I feel like was a big way to get them to learn or like build a personal connection."

*Demonstrations.* A second instructional strategy was to provide demonstrations of the activities. Toward the end of the first semester, Alexander began making short videos demonstrating one way to complete the design challenges. He explained he wanted to "attract their attention" and to offer them a resource they could "rewind or move back." In spring 2021, Alexander continued to make the video demonstrations but purposefully would leave out steps to spur discussion. He explained, "I would show them a clip of the demo so my actual demonstration, and I started leaving things out, and then I would ask them, 'So, what can I improve? What can Mr. Alexander improve?'" He noted that the resulting conversations stimulated students' cognitive engagement in the form of creativity: "I would actually leave them some space for creativeness and also some space for critical thinking."

The demonstrations engaged only a few of the students (three), who mentioned watching the videos to understand how to do the build. Their responses, however, suggest that while the videos may have increased behavioral engagement—they also may have decreased students' cognitive engagement. For example, Lorena told us she watched the videos so,

> I could know I could do it, I could do the project, I had motivation to do it well, and then maybe I could copy his design, but not really, just add some things he didn't add, and with the advice, like he's saying some advice, "Hey, don't do that," or, "Hey, don't do this."

*Feedback and Encouragement.* The mentors' third and final instructional strategy to boost engagement was to offer their students feedback and encouragement on their designs. The mentors started providing feedback in spring 2021 by splitting up the students and working on the designs in breakout rooms. Abaeze described how he used the sessions: "I would try to give them some tips on how to make it better and how to look at it from a different perspective." Roberto told us that the purpose of the small group sessions was to "lock out their design and look at their design and be like, 'Hey, how's everything going? What's going on?'" He concluded by saying, "I think that's how the engagement really changed." The mentors also asked the students to comment and give feedback on each other's project designs while in breakout rooms to cultivate their social engagement. This strategy had mixed effects on students' social and cognitive engagement. Some students were eager to help each other and give feedback, offering constructive advice. Other students, however, were more reserved and only encouraged their peers, for example saying that the other students' projects looked good.

When we talked to the students, we heard from five about how the feedback encouraged behavioral engagement (completing the engineering design process) and cognitive engagement (creativity and evaluating alternative designs). For example, Henry explained that the mentors helped "by giving me information and by helping to know which tools that are best to use." Alejandra described how the feedback pushed her to consider alternative designs and materials and to test the different designs:

> I was really thinking of doing—like the thing that I told you, the square, but they said, "Why don't you try something else." So, then I told them that I was going to try it out to see if the square worked or not, and they said okay, and then they told me another option that I should do, the rectangle one or the triangle, and then all that. So, I tried the square, and then the triangle, and then the rectangle, and I liked the rectangle better.

*Social Role.* An important role that the program mentors take on—and that the program manager encourages—is social. As a face-to-face program, the program manager has encouraged the mentors to play a social role (see Snodgrass Rangel et al., 2022). However, given the isolation that the students and mentors experienced in 2020–2021 during online learning, the program manager placed even more emphasis on this role. One specific practice the mentors implemented in the fall of 2020 was checking in with students at the beginning of each session. For example, Isaac, whose experience was representative, characterized the check-ins in the following way:

> So, the activities the students really enjoyed of course right off the bat, check-in. Just literally checking in with the kids. "How was your day?" "Anything fun happening with you guys?"…The kids really enjoyed that.

Roberto pointed out that these interactions—though usually not focused on engineering—were crucial for building relationships with the kids, which he acknowledged was particularly valuable given the mental health issues many students experienced during the COVID pandemic.

The mentors' focus on building relationships with the students led the students to be more socially and behaviorally engaged. For four of the students, the social engagement revolved around a shared interest, which they learned about through regular check-ins. For example, Henry told us how he liked the mentors because they were funny and because, like him, they also liked "cool cars" and drawing. Lorena also noted that she connected in particular with one of the mentors because of their shared interest in food—"the $2.50 from Walmart, the cherry pie, that's both of our favorites"—and she connected with another mentor because "he's very good at math and I am good at math."

*Managerial Role.* The mentors also played managerial roles, seeking to keep students engaged through managing the online environment. The four ways we observed and heard about the mentors enacting managerial duties were reviewing behavior expectations, redirecting students, pulling them aside to address misbehavior, and using incentives to encourage participation. In this role, the mentors increased behavioral engagement and got more students to pay attention and participate.

The mentors reviewed the program's shared norms regarding behavior before each session. As they reviewed the expectations, the mentors asked students to take turns reading the expectations out loud, leading the students to become more behaviorally engaged because the students figured out the mentors might call on them. The mentors also reminded students before the SOW and the presentations to be respectful, pay attention, and raise their hands or use the chat for questions.

As with any classroom environment, the students were sometimes off-task, and the mentors found ways to redirect and re-engage them. Instances of off-task behavior ranged from students turning their cameras off, students spinning in office chairs, and students playing video games. All the mentors described instances where they had to re-direct the students. As an example, Isaac described how he would call on them to participate: "So, to engage them, just simple cold calling worked so well." Alexander recounted how he sent private chats to students who did not seem to be paying attention or even turned their cameras off: "If I saw that a student wasn't paying attention, I would send them a private chat like, 'Hey, let's try to focus,' like something really low key."

If the mentors decided that their redirecting efforts were not working or that students' behavior warranted more intervention, they used the breakout rooms. For example, Abaeze recounted how "there was an incident with a student to where I felt like he was being a little disrespectful, but I guess he wasn't seeing it that way. So, I had to pull him into a private room and talk to him about it." Roberto described using a similar strategy but, acknowledging the challenging moment they were all living through, added,

> It wasn't a stern thing. It was just kind of like, "Hey, what's going on? Is everything okay?" Is everything okay at home, basically? Like, "What's going on? Why aren't you engaged today? Is there something else going on?" Just talking with them.

Based on our observations, the mentors' redirecting strategies resulted in more behavioral engagement (i.e., cameras switched back on, eyes back on the camera, no more spinning); however, it was not clear that the mentors were able to re-engage students cognitively when they were bored.

Finally, the mentors described using incentives to encourage participation. The incentives included voting for the student of the week to reward the best effort on a build and actual prizes. Alexander described the mentors' thinking about the use of incentives to encourage and reward engagement with the program and the projects, telling us, "We also tried to give prizes out for kids who did really well and paid attention… I would be like, 'You're getting something,' just for paying attention and participating and stepping forward." The incentives helped with behavioral, emotional, and cognitive engagement. For example, naming a student of the week led students to complete their projects (behavioral engagement). The incentive to win student of the week led Henry to stay up late on a Friday night to complete a build: "I did it on a Friday just before Saturday and there's a lot of pressure." It also led Lorena to feel pride about her work (emotional engagement) because winning student of the week made her mother excited: her mother "only got excited because I only won student of the week."

### *Learning Environment and Affordances*

The online learning environment had both benefits and drawbacks for student engagement in the program. In this section, we highlight the drawbacks, including the lower levels of interactions and distractions, and the benefits, such as the value of small-group and one-on-one meetings in the breakout rooms.

#### *Drawbacks of Learning Online*

In general, the students and mentors experienced the engineering program online as less engaging than they imagined the program would have been in person. To be clear, the students and mentors enjoyed the program but still identified how the online learning environment decreased engagement. From the mentors' perspective, they struggled to keep the students behaviorally engaged without being physically present. Isaac explained,

> I knew it was already going to be a challenge simply because we're not physically in a classroom. I can't go up to them at their desk and help them. Even like something as simple as me cracking a joke was not going to land that hard if I'm just behind the screen. I'm basically just like this virtual person and a lot of the children were new to the program and not being able to physically meet them I think was definitely a hindrance.

They also believed that holding the program online affected the students' social engagement with the program and each other. As an example, Hai shared the following:

> I didn't feel it. I didn't feel like I was being a mentor last semester because I didn't have any strong connection with them because we have the screen in front of us. You can't really tell how they feel or what they're thinking to a screen.

The students also felt isolated, which affected their social engagement. Lorena exemplified this ambivalence in the following response:

> So, it wasn't boring, but at the same time, it kind of was because we're not together, …but it was kind of like boring that we didn't get to be together because COVID, but all in all, it was actually really fun.

Finally, several students experienced technical problems. These included students having trouble logging into Zoom, frozen computers, and slow internet. Students experiencing technical issues could not engage at all with the program content and activities to the same extent as students with fewer or no challenges. For example, Hector and Luis, two brothers who logged on from their afterschool program, experienced connectivity issues. Hector explained, "I mean sometimes we were lagging."

*Online and Offline Distractions*

Online and offline distractions also affected students' behavioral and cognitive engagement. Throughout our observations, we could see that the students were distracted, looking off-screen at other things on their computer or around the room, spinning their chairs in circles, resting their heads on the computer or their arms, playing video games, interacting with family members or schoolmates, or eating and drinking. For instance, we observed how a student drinking a bottled soda began using the cap to take "shots" of soda as the SOW presented.

For those students logging in from home, these distractions included toys and video games. For example, Henry told us,

> There is this one time when I was playing on my PS4, I have a PS4, and it was time to get into STEM… I got a little distracted because Fortnite and Minecraft are very hard to not get distracted from.

As we described in the previous section, the mentors noticed when students were distracted and felt frustrated by the distractions.

Another source of distraction was other people around the students. Sarah and Alejandra admitted that joining the program from home was distracting because they had siblings who wanted to play with them. Similarly, Hector and Luis joined from an afterschool program, where participating in the online engineering program meant they were missing out on other organized activities with their friends. Grace and Marcus both joined from their school, where they often distracted each other.

Finally, students were distracted by being on the internet. Several mentioned that they were tempted to search the internet and look for favorite videos or web pages. Jose told us that having access to the internet was distracting for him. When we asked him whether he felt distracted sometimes during the program, he told us, "Maybe some things that are going on the background, things from the web. Things that I would just be thinking randomly all day." We also observed how, at times, students were looking at the screen as though they were paying attention but were reading or interacting with the screen in ways that did not make sense. These distractions meant that students sometimes were not listening and, therefore, could not engage at all.

*Breakout Rooms*

The effect of the online nature of the program was not entirely negative. Indeed, the breakout rooms facilitated meaningful social, emotional, cognitive, and behavioral engagement. The mentors used breakout rooms to redirect students, help them with their designs, provide feedback, and connect with students. Because we have described the first three already, here we focus on the third use of breakout rooms—to foster social and emotional engagement. When mentors met with students in breakout rooms, they usually met with no more than two to three students. Alexander explained this benefit, saying, "we would go out in the breakout rooms, so it is a little easier to engage a student when you're one on one with them instead of like six." We also observed an increase in student–mentor and student–student interactions with the breakout rooms. The students asked more questions and interacted more frequently and meaningfully with each other.

The mentors also noted that the breakout rooms supported deeper social engagement than did the main Zoom room. For example, Hai met with Lorena in a breakout room during one session when Lorena was crying. Hai described how she found out that the student had lost a family member,

> I'm not good at like consoling people. So, I'm just sit there and like, "Don't cry. Everything is going to get better soon." Then we talked about what she's interested in like anime and stuff. Then she got so excited again. So, then we kept on talking about it and stuff like that. She's also a foodie… That's really similar to me, I like to eat food too… That's how we created a bond.

The students shared these sentiments. Lorena noted fewer distractions and explained, "I go to talk a little bit even more when I'm in a small group. So, I get to express all my ideas when we're in a small group." Lorena also shared her interaction with Hai and her support in the breakout room.

Another affordance was the portability of the program because it was online. Students' ability to join online and while "on the go" improved behavioral engagement for those students who literally were on the move. For example, we observed that one student joined from his mother's car and another day from the grocery store. The portability of the program made it more accessible to students who otherwise might have missed sessions.

### *Nature of the Activities*

In this section, we describe how the nature of the activities shaped students' engagement. We discuss the level of autonomy and creativity that the activities facilitated, how interactive the activities were, and the age appropriateness of the activities.

#### *Autonomy and Creativity*

The open-ended nature of many of the design challenges drove students' behavioral and cognitive engagement. Just under half (five) of the design challenges did not have a single solution or a predefined set of materials (the remaining seven called on students to follow directions to create or build something and therefore offered less opportunity to be creative or improvise; see Table 1). Though the program sent the students a basic kit with many materials, the mentors encouraged them to use found objects around them to complete the builds. This autonomy increased students' cognitive engagement as they got to be more creative. For example, Marcus had the following response when we asked whether he enjoyed getting to pick which materials he used and how he used them: "Yes, I liked it." Jose explained he got to be creative because "they had a limited amount of resources. I had to use them in ways that sometimes were a little unconventional."

The mentors observed the increase in cognitive engagement associated with more open-ended builds. For example, Roberto described how he loved to see the students' creativity when they presented their builds on Saturdays. He said, "I think the Saturday programs and their actual execution of the design really does show the imaginary mind of a kid because you really do see these elaborate designs of what have you." Hai agreed that the open-ended activities sparked students' creativity and were the most enjoyable. She told us,

> I think one of the experiments they like the most is making toys out of the things at home because that is one a lot of students participated in, and they were being very creative. That's something that we like the most.

Another driver of students' cognitive engagement was the inclusion of design specifications for each build. The specifications comprise technical requirements that the design must meet to ensure the usability and feasibility of the final product. Because the specifications constrain the options available to the students, it fosters creativity. For example, Marcus described the specifications he had to consider when building his shoe:

> [The shoe] also had to require a lot of building steps and a lot of like, are they comforting, how to run it, how to run, and how fast it can go. It had to have three things, too. Comfortability: it had to protect your foot and it would have to make you run fast.

The mentors also commented on how the design specifications increased students' cognitive and emotional engagement. For example, Abaeze explained that he thought the students liked the miner rescue build because the specifications made the student competitive:

> Even though [the build] was kind of straightforward, the amount of intuition that you have to do to build a crank system or something like that, the set rules that was in front of us, it was kind of like a competition in a way.

In contrast, the mentors and the students described less behavioral and cognitive engagement with two activities that were not open-ended. For example, one of the early activities in spring 2021 called on students to build a magic wand by creating a circuit. One of the students described being disengaged, noting that the build "was not interesting." The mentors also criticized the magic wand, noting that it did not allow for much creativity:

> You can't really be creative with the circuit. If you get really creative, it might just not work. So, it's a lot stiffer in the sense that it's a lot narrower in the sense that you don't have a lot of wiggle room.

*Level of Interaction*

Though the builds were very interactive, other program activities were not and, therefore, depressed student engagement. We found that the students were disengaged during any opportunity when they were listening and not actively participating in an activity or interacting with another student or a mentor. For example, Jose told us he was bored, "When they're presenting a lot of the projects. When they're talking about what we're supposed to be doing that week, I just found that really boring." Grace agreed, explaining, "It's just the talking that I get bored." She went on to elaborate that she often found the SOW visit boring "because there's so much talking… It's like they're robots." Henry had a similar experience, admitting, "Sometimes, I would like snooze off or something like that because there was a lot of interview with people from the [company]. It was getting a little boring." The mentors were aware of how disengaged some of the students became when there was a lot of talking. Isaac described what he observed: "We would be looking at the kids during SOW. They're just lost, dude. You look at their cameras, they're zoning off. I don't know what they're looking at."

*Age Appropriateness*

A final contributor to students' engagement—or disengagement—was the age-appropriate nature of the math problems and the SOW presentations. For most of the students—with one exception—the math problems and the SOW presentations were too advanced. Indeed, one of the reasons that the students found the SOW boring was that they did not always understand the scientists and engineers. Hai described how sometimes she even felt lost during the presentations, and she is an engineering major: "I was slightly interested until he starts speaking numbers… I didn't even know what it meant. If I didn't even know what it meant, I can feel why the kids are not so interested in it."

As a result of these early experiences in the fall, the mentors tried to give more specific guidelines to the guests so their presentations would be more appropriate. Isaac recounted how they reminded the scientists that the students were young and needed them to use simpler language. He said,

> We tried telling them like, "These are fourth and fifth graders. They're not going to understand what a combustion chamber is." Or "they're not going to understand what polyurethane is or anything like that." You need to really break it down to a level in which they can understand.

The math problem of the week often was too challenging, though how that affected students' engagement differed. Alexander explained, "We definitely were a little ambitious with the difficulty. There were very few students that could answer them easily at first and then, we softened it up a little bit." Some students embraced the challenge because they liked math and believed they were good at it. For example, Alejandra told us, "There was one hard part when it was like you need to add it, then subtract it, and then get the thing you can—I'm still practicing on it." Other students, however, had difficulty staying engaged because they did not understand the math. For example, in the fall of 2020, the mentors assigned a math problem that included exponents, which not all students were familiar with. We observed how the mentor tried to explain and apply exponents, but the student became behaviorally and cognitively disengaged, sitting further back in his seat and staying silent. In another example, we observed how a mentor tried to help two students solve an algebra problem. Neither student knew how to solve the problem; one tried to stay engaged, writing away on their paper, but the other student looked confused and repeatedly looked between their paper and the screen.

## Discussion

*Implications for Research*

Our study fills an important gap in understanding how elementary students engaged with engineering learning during the COVID-19 pandemic. Through our case study of an online informal engineering program, we contribute to research on engineering education, student engagement, online and informal learning, and the effect of COVID-19 in multiple ways.

The students generally were engaged with the engineering activities across all four dimensions of engagement. In this way, we describe how student engagement manifested in online learning when school engagement was uneven at best (Domina et al., 2021) and low at worst (Burke, 2020; Hamilton et al., 2020; Oberg & Rafique, 2020). At the same time, we highlight engagement challenges the program and its staff faced, in part because of the online learning environment. Second, we offer evidence of the factors that enhanced engagement in elementary engineering education in the context of online informal learning, an area where there has been little research. Third, we connected the factors to the specific engagement domains they affected, something that very little prior research on online or engineering education does.

*Social Engagement*

Our findings on social engagement offer new insights into how informal online programs can enhance social engagement. Despite the online nature of the program, the students were very socially engaged with the mentors, but less so with their peers. When the program is face-to-face, there typically is a great deal of peer collaboration and socialization, but this was missing from most sessions. We speculate that the decision to combine schools because of the low enrollment within each school due to COVID meant that students did not know each other and had no existing relationships to build on in the online environment. We also wonder whether the fact that the students completed the builds on their own at home and not together in a classroom because of COVID prevented the types of social interactions that take place when the program is face-to-face.

The factors that increased students' social engagement included the mentors' teacher roles, Zoom's affordances, and the nature of the activities. Our findings are consistent with prior research, including research from online learning during COVID, which points to teachers' social role (Cleveland-Innes & Campbell, 2012; Molinillo et al., 2018; Pentaraki & Burkholder, 2017) and their use of technology affordances, such as chat features (Abou-Khalil et al., 2021; Anderson & Hira, 2020) and cell phones (Anderson & Hira, 2020), as factors that enhance social engagement. We add to these previous studies with our finding about how important the mentors (in their social, pedagogical, and managerial roles) were for students' social engagement, above and beyond the nature of the activities and the learning environment. In fact, because we found that students very rarely interacted with each other, we conclude that the mentors were instrumental in building the relationships and trust that then facilitated students' social engagement and their behavioral and cognitive engagement in the program's activities.

In line with previous research, we also found that taking advantage of the platform's affordances enhanced social engagement. However, unlike Abou-Khalil et al. (2021) and Anderson and Hira (2020), we found relatively less use of the chat feature and more use of the breakout room feature to stimulate social engagement. The reliance on the breakout room may have been related to purpose—having private conversations with students and meeting to review progress on the builds; the chat function likely would not be effective for either of these purposes. We also add to existing literature with our finding that the interactive nature of the activities shaped social engagement. Given the online nature of the program, the builds were very interactive because the students had to build them with physical objects and their hands. The builds, therefore, diverge from many models of online learning and more closely parallel face-to-face STEM programming. Researchers should continue to study similar hybrid models and the impact on different dimensions of engagement.

*Cognitive Engagement*

We offer new insight into the factors that influence cognitive engagement in online engineering education programs. Existing research notes that the mentors' social teaching roles encourage risk-taking in students (Chiu, 2021; Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016), while teachers' pedagogical decisions can enhance student autonomy and choice, which are related to higher cognitive engagement (Alamri et al., 2020; Bedenlier et al., 2020; Ingulfsen et al., 2018). Moreover, activities that students perceive as more relevant also engage students cognitively (Louwrens & Hartnett, 2015). In general, our findings were similar—the two drivers of students' cognitive engagement were the mentors' teaching roles and the nature of the activities. The mentors' use of questioning and feedback challenged the students to work harder and think deeply. We did not see direct evidence that mentors' social teaching role resulted in more cognitive engagement. However, mentors' social teaching role likely cultivated trust among the students, supporting risk-taking and a greater willingness to persist through challenging work. Future research should continue to explore the relationship between teachers' roles and student cognitive engagement. The nature of the builds was instrumental in shaping students' cognitive engagement. Open-ended builds and design specifications challenged students to be creative with and test multiple designs. We also showed how one of the mentors' support strategies, video demonstrations, did not challenge students cognitively in the way they hoped. Future research should continue to explore how teachers can incorporate exploration and open-ended tasks into informal, online learning.

### *Behavioral Engagement*

Our findings also speak to how programs can support students' behavioral engagement. Researchers have highlighted several factors, including student interest (Milligan et al., 2013), the mentors' social (Chiu, 2021; Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016), pedagogical (Chiu, 2021; Vansteenkiste et al., 2009), and technical (Frederick et al., 2020) teaching roles, and the learning environment (Bergdahl et al., 2020). Our findings are consistent with previous research—highlighting how the students' interest resulted in attendance and participation, the mentors' pedagogical teaching strategies encouraged discussion, and the learning environment often was a source of distractions. We also add to the extant literature with our finding that the interactive nature of the builds and the mentors' use of incentives stimulated behavioral engagement for some of the students.

### *Emotional Engagement*

Finally, our findings also add to the field's understanding of how to support emotional engagement. We observed that students were emotionally engaged with the program: they had fun and felt a sense of belonging. Previous research on factors that cultivate emotional engagement in online learning identifies the social role teachers play in supporting student enjoyment (Chiu, 2021; Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016) and sense of belonging (Ascough, 2007; Shea & Bidjerano, 2014); teachers' pedagogical role fostering autonomy (Skinner et al., 2008); and teachers' use of affordances (Anderson & Hira, 2020). Our findings both support and add to this existing research base. We found that the mentors' enactment of their social teaching role through regular check-ins enhanced students' enjoyment as they discovered shared interests and joked around. We also found that breakout rooms supported emotional engagement as they facilitated relationship-building and helped students develop a stronger sense of belonging in the program.

We found that student interest and the nature of the activities also contributed to emotional engagement. Student interest was related to excitement and enjoyment. The nature of the relationship between the activities and emotional engagement, however, was less straightforward. On the one hand, the hands-on nature of the builds was associated with students having fun and enjoying the program. On the other hand, the Saturday presentations made some students feel nervous about sharing their work. We speculate that the generally positive emotions students experienced were an artifact of the program's voluntary nature; future research should examine students' emotional engagement in non-voluntary engineering learning programs to see whether more negative emotions such as anxiety or frustration are more present.

### *Engagement versus Disengagement*

Though we observed many instances of positive engagement throughout afterschool program during the year it was fully online, we would be remiss if we did not reflect on the instances of disengagement. Disengagement manifested primarily as behavioral: students were bored, stopped paying attention, and zoned out. We connected these manifestations of behavioral disengagement primarily to the nature of the activities: some were boring, others expected students to be relatively passive, receiving information (i.e., SOW), and others were closed-ended or structured, which stifled creativity. As important, we did not observe or hear about instances of cognitive disengagement (e.g., students giving up quickly on a task), emotional disengagement (e.g., feeling frustrated or overwhelmed), or social disengagement (e.g., not caring about the people in the program). It may be that students did not share their negative experiences or feelings or that we did not observe them giving up on a build. It also could be that the fun and social nature of the program helped distract the students, even if just briefly, from stressors in their lives and motivated them to persist. It also could be that students who were cognitively, emotionally, and socially disengaged in school generally did not participate in the online program during COVID.

The question of disengagement in informal STEM learning warrants more investigation. For example, researchers have tied cognitive disengagement to stress (e.g., Jopling et al., 2021), depression (e.g., Bowie et al., 2017), cognitive load (e.g., Bowie et al., 2017), and burnout (e.g., Basinska & Gruszczynska, 2020; Kroska et al., 2017; Wang et al., 2015). Importantly, during the pandemic, researchers documented an increased in each of these in young students as a result of social isolation, "Zoom fatigue," sickness, and the loss of friends and family members (e.g., Liang et al., 2020; Luthar et al., 2021; Salmela-Aro et al., 2021; Tomaszek & Muchacka-Cymerman, 2022). Indeed, at least one student admitted that sometimes they were not motivated to log onto the program after seven hours of online learning because they were tired of sitting in front of a computer and being on Zoom. We recommend that researchers dig deeper into disengagement among young learners during COVID generally and the drivers of disengagement in informal STEM learning, both online and face-to-face, more specifically.

### *Peers as a Driver of Engagement*

We conclude our implications for research by reflecting on why peers were almost entirely absent from our analysis. Prior research on the effects of peers has produced mixed findings, suggesting that the relationship between peers and engagements is moderated by the nature of the peer interactions (e.g., Cappella et al., 2013), the teachers' presence (Nguyen et al., 2018), and, in online settings, the ways students are able to interact with their peers (e.g., chat, badges, thumbs-ups; Abou-Khalil et al., 2021; Ding et al., 2017). Our findings are quite different in that we found very little peer interactions at all and so we were unable to discern a relationship between peer interactions and engagement. There are two reasons that likely explain the lack of peer interactions. The first was that many students did not know each other prior to the program because they attended different schools. The lack of prior relationships may have inhibited peer interactions. Second, we speculate that the lack of group work, which is a normal feature of the program when it is face-to-face, meant that students did not have natural opportunities to interact with each other during the program activities. The irony of our finding is that the program had the explicit goal of fostering social interactions among the students because of the social isolation of COVID; however, the reality of social distancing and learning online from home meant that students were unable to work together. We need more research on peer interactions in the context of online learning during COVID given how widespread were social isolation and mental health problems (e.g., Liang et al., 2020; Luthar et al., 2021; Salmela-Aro et al., 2021; Tomaszek & Muchacka-Cymerman, 2022).

*Limitations*

As with any study, this had its limitations. First, our study comprised a single case with a small number of participants, limiting our ability to generalize the findings and implications. Moreover, the program was not created during COVID; instead, it was an existing program that transitioned online. The program, therefore, had a solid foundation to build on in terms of how it sought to maximize students' engagement with engineering learning. Third, participation in the program is voluntary. Therefore, strategies that enhanced engagement for the students we describe might not work for an online class, where attendance is not voluntary, and the students may not have the same level of interest in the content. Finally, though Zoom gave us the unique ability to video record sessions non-intrusively, it also created challenges, which we discussed above.

*Implications for Practice*

Though most educators, students, and families alike are eager to return to fully face-to-face learning after the pandemic, the increased integration of technology in and out of schools during the last two years is unlikely to be rolled back completely. For that reason, our study has implications for online, hybrid, and face-to-face programs. In this section, we offer recommendations relating to instructional design and social engagement. Our recommendations reflect many best practices for informal face-to-face and formal online instruction but are particularly important given the distractions students encounter and the constrained level of interaction typical in online environments.

*Instructional Design*

We recommend that informal online engineering and other STEM programs use careful instructional design to enhance student engagement. First, part of the programming should be synchronous. Studies of formal online learning during COVID suggest that students were more engaged when they had more opportunities to interact with peers and instructors (Kurt et al., 2022; Lazareva, 2018; Tsai et al., 2021). Our findings were similar, highlighting the importance of students' myriad interactions with the mentors. Further, there is evidence that asynchronous programming, which offers students flexibility, may not engage students in the same way that synchronous learning can (Zhao & Kuh, 2004). Therefore, we discourage informal online STEM programs from being fully asynchronous.

Second, program designers also should attend to the nature of the activities they offer. Specifically, we recommend they incorporate hands-on activities that are more open-ended. Research in science and engineering education demonstrates that students should engage in scientific and engineering practices (National Research Council, 2012a), as they do in the engineering design process (Bethke Wendell & Rogers, 2013; Gibson, 2003). Students also enjoy (Hyun et al., 2017) and are more engaged in their learning when that learning is active (Barkley & Major, 2020; Chen et al., 2008; Jamaludin & Osman, 2014; National Research Council, 2012a; Smith et al., 2005). Therefore, having students engage in the engineering design process directly and through hands-on activities is likely to boost student interest and make engineering more fun for students. These hands-on activities also should be somewhat open-ended because having autonomy and choice stimulates students' engagement (Archambault et al., 2020; Jang et al., 2010; Reeve et al., 2004).

*Social Engagement*

We also recommend that online programs emphasize social engagement because of the isolating nature of online learning, which was exacerbated during COVID. Social engagement can occur because of the instructors' efforts to interact with students or peer-to-peer interactions. Researchers have outlined multiple benefits students accrue as a result of these social interactions, including attention to students' social and emotional learning needs (Cleveland-Innes & Campbell, 2012; Pentaraki & Burkholder, 2017), the creation of a safe space (Carr, 2014) where students feel they belong (Ascough, 2007; Shea & Bidjerano, 2014), and enhanced enjoyment (emotional engagement) (Chiu, 2021; Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016; Vollet et al., 2017; Young & Bruce, 2011). We have highlighted multiple strategies that enhanced social engagement, particularly between the students and mentors, such as informal check-ins and small-group breakout sessions. Online STEM programs also should seek ways to engage peers with each other, for example through collaborative projects (Abou-Khalil et al., 2021) and the use of badges, thumbs-ups, and avatars (Ding et al., 2017).

*Mentor Training*

Finally, we recommend that program designers offer training and ongoing support to the people leading the informal learning. In the case of the program we studied, undergraduate STEM majors acted as instructors and mentors. Therefore, the program manager required training each semester. We describe the training and ongoing support the mentors receive above; however, we found that the mentors would have benefitted from additional training that focused specifically on pedagogy, classroom management, and social engagement in an online environment. The program manager addressed these three topics ahead of the spring 2021 semester and we recommend that other online STEM programs draw on existing research on preparation to teach online learning (e.g., Brinkley-Etzkorn, 2018; Shattuck & Anderson, 2013) to prepare their program instructors for the differences in the learning environment and students' social and emotional needs.

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## Appendix A

### *Codes*

*A priori* codes:

- Behavioral engagement
  - Disengagement
- Cognitive engagement
  - Disengagement
- Emotional engagement
  - Disengagement
- Social engagement
  - Disengagement

Emerging codes:

- Communication
  - Mentor-to-mentor
    - i. Social: Anything related to communication not specific to work, friendship
    - ii. Help: Anything related to how they asked each other for help, offered help/mentorship, need for more help
  - Mentor-to-student
    - i. Social: When a mentor(s) talks with one or more students about something other than STEM or the program
    - ii. Help: When a student asks a mentor for help, or a mentor offers/provides help to a student
  - Mentor-to-parent
    - i. Lack: of communication with parents
    - ii. Challenges: of communication with parents
    - iii. Positive examples: of communication with parents
- Value of virtual
  - Benefits: Examples or descriptions of the benefits of being virtual this year
  - Drawbacks: Examples or descriptions of the drawbacks of bring virtual this year
- Engagement strategies: Actions the mentors took to get the students engaged in the session
- Barriers to engagement
  - Virtual environment
  - Programming/components
    - i. Age appropriateness
    - ii. Disorganization
  - Distractions for the kids
- Benefits to the mentors
  - Time management: Examples or descriptions of how participating as a mentor has improved their time management skills
  - Break:
    - i. Break from school: and hard work
    - ii. Break from isolation: of online learning and COVID
  - Joy: of working with kids
  - Professionalism: learning to give presentations, to manage/collaborate with others
- Parent engagement: Examples and descriptions of how parents engage during sessions
- Parent disengagement: Examples and descriptions of how parents do not engage during sessions

- Mentor collaboration: Examples of the mentors working together and helping each other around the program
- Program components
  - Math problem of the day
  - Scientist of the week
  - Design/build
- Nature of activities
  - Open-endedness
  - Purpose
  - Materials
- Reason for joining

**Appendix B**

*Interview Protocols*

*Mentor Protocol*

1. How has your semester gone? How did it compare to the fall?
   a. What changes did you all make this semester relative to the fall, and what do you think the impact of those changes was?
   b. Was there more parent/family participation this semester? What was different? How did the parent/family engagement/participation change the program (if at all)?
   c. What were some of the challenges you encountered this semester? How did you resolve them?
   d. What were some high points from the semester? What made them stand out to you?
2. *I'm going to ask you about the activities you all worked on with the students this semester. For each activity, please start by describing each activity generally—who was doing what, etc.* [be prepared to remind them of this prompt] How did the STEM activities go this semester online compared to last fall?
   a. Social/informal time to chat with students [*What were some of the things that you talked about, what did students bring up, how did the students react to this time, how did it make you feel?*] [Social and/or emotional engagement]
   b. Design break-out rooms
      i. *What were some of the things you talked about with/asked the students? How did the students react to your questions and suggestions?* [Behavioral and cognitive engagement]
      ii. *How did adding these break-out rooms change students' engagement/participation and what they ended up building?* [Behavioral and cognitive engagement]
   c. Builds
      i. W*hich ones did the students ask for help with? What type of help did they ask for?* [Behavioral engagement]
      ii. *Which ones did the students seem to like more and less? How could you tell they liked/disliked it, and why do you think they liked/disliked it?* [Emotional dis/engagement]
   d. Math [how did this compare to last fall?]
3. Were there times when the students seemed less engaged or bored? When? How did you address or redirect the students? [Behavioral and emotional engagement]
4. Did you feel more or less connected to the students this semester compared to last semester? What was different that led to more/less connection with the students? [Social engagement]
5. How did working with the kids in the STEM program affect your life and schoolwork this semester? How did it compare to last semester?
   a. How did working with STEM affect how you view the University (if at all)?

6. Our last question is about the training you received at the beginning of this semester. Did you feel more prepared to facilitate the program online this semester?
   a. What additional training or support would be useful considering the program will be online again in the fall?
7. Is there anything else you'd like to add?

*Student Protocol*

1. What are your names, what school do you attend, and what grades are you in?
2. How did STEM go this semester?
   a. What has it been like to do the STEM program online? What did you like about doing STEM online, and what did you not like about doing it online?
3. Were you excited about the days you had STEM? Why or why not?
   a. What made you feel excited during STEM? [Emotional dis/engagement]
4. Can you tell me about when you worked on math during STEM?
   a. What kinds of math did you do?
   b. What did you like about working on math, what did you not like about it? [Emotional dis/engagement]
5. Can you tell me about when you met with the mentors in smaller breakout rooms to discuss your designs?
   a. Was it useful to meet with the mentors like this?
   b. What were some of the questions you had? [Behavioral dis/engagement]
   c. What were some changes you made to your designs after the meetings? [Cognitive dis/engagement]
6. Did you ever watch the videos that the mentors made about the builds?
   a. What did you think of them?
   b. Were they useful? Why or why not?
7. What was your favorite activity? Can you walk me through what you did?
   a. Why was that your favorite activity? [Emotional dis/engagement]
   b. Did you like building things on your own? [Cognitive dis/engagement]
   c. How did you decide what materials to use? [Cognitive dis/engagement]
   d. Did you feel like you got to be creative? [Cognitive dis/engagement]
8. What was the most challenging activity? Can you walk me through what you did for the activity? [Cognitive dis/engagement]
   a. Why was that challenging? [Cognitive dis/engagement]
   b. How did you figure it out? [Cognitive dis/engagement]
   c. Did you have some help to figure it out? (From whom?)
9. Was it hard sometimes to pay attention to what was going on in the STEM session on Zoom? [Behavioral dis/engagement]
   a. What were some things that distracted you? [Behavioral dis/engagement]
   b. Did you ever feel bored during STEM? [Emotional dis/engagement]
   c. If we could change anything about the program so that you're not bored, what should we change?
10. Did someone in your family ever participate in STEM with you, or help you with what you were making?
    a. How did they help you?
    b. How did it make you feel to have help from that family member? [Emotional dis/engagement]
11. Who was your favorite mentor and why? [Facilitate emotional engagement]
    a. What was it like to work with the mentors online?
    b. Were the mentors able to help you with the projects? [Facilitate cognitive and behavioral engagement]