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Justina R. Jackson
Georgia Institute of Technology, justina.jackson@ceismc.gatech.edu

Katherine L. Boice
Georgia Institute of Technology, katherine.boice@ceismc.gatech.edu

Stephen Cochran
School District Partner for GoSTEAM@Tech, stephen.cochran@gcpsk12.org

See next page for additional authors

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Abstract

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Keywords

pre-college engineering, STEM/STEAM education, Covid-19, K-12 emergency remote teaching (ERT), virtual instruction, narrative analysis

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Authors

Justina R. Jackson, Katherine L. Boice, Stephen Cochran, Brooke Skelton, Jeffrey Rosen, and Marion Usselman

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School Personnel Lived Experiences Related to High School Engineering Education and the Covid-19 Pandemic

Justina R. Jackson[1], Katherine L. Boice[1], Stephen Cochran[2], Brooke Skelton[2], Jeffrey Rosen[1], and Marion Usselman[1]

[1]*Center for Education Integrating Science, Mathematics, and Computing (CEISMC), Georgia Institute of Technology*
[2]*School District Partner for GoSTEAM@Tech, Georgia, United States*

Abstract

This study investigated the teaching experiences of three school personnel at a public high school during the 2020–2021 school year as they implemented a unique science, technology, engineering, arts, and math (STEAM) unit with in-person and virtual students in their engineering classes during the Covid-19 pandemic. A research team interviewed two teachers and one administrator at the school to better understand the nuances of pre-college engineering during a pandemic year and how changes in school and district policy affected the instructional delivery of STEAM projects. Narrative analytic methods were utilized to understand each participant's experience and an inductive content thematic approach was used to develop the findings. The participants described varied experiences navigating instruction during the pandemic, particularly when adapting hands-on STEAM projects for virtual or hybrid teaching. All three participants thought deeply about how to best meet the needs of students while attempting to support equitable instruction. The findings of this study indicate that pre-college engineering in the pandemic was challenging for the participants, but not impossible, and that this setting was an appropriate context for STEAM projects that provided students with a mechanism for collaboration and engagement.

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In March 2020, the Covid-19 pandemic forced school closures across the United States, causing teachers to make a quick transition from in-person schooling to virtual teaching. For many K-12 public-school administrators and teachers, this meant adjusting policies and expectations for instruction, curriculum coverage, and grading, while addressing challenges related to accessing adequate technology, materials, and reliable internet (Hamilton et al., 2020; Reich et al., 2020). The following school year marked the first full academic year of teaching during the Covid-19 pandemic. Though some schools returned to in-person learning in fall 2020, others remained remote, while still others offered a "hybrid" option, in which teachers instructed virtual and in-person students concurrently during the same class period. Teachers tasked with providing virtual or hybrid instruction often did so with little previous experience or training and faced challenges with student access to adequate technology or reliable internet, low student engagement and accountability, and providing rigorous instruction (Kraft et al., 2020; Marshall et al., 2020; Reich et al., 2020; Reid & Griesinger, 2021).

Authors' Note: We have no known conflict of interest to disclose. Correspondence concerning this article should be addressed to Justina R. Jackson, Center for Education Integrating Science, Mathematics, and Computing (CEISMC), Georgia Institute of Technology, 505 10th St NW, Atlanta, GA 30332-0282, United States. Email: justina.jackson@ceismc.gatech.edu

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Engineering education provides an interesting context in which to examine the impacts of the pandemic. The very nature of pre-college engineering courses poses challenges for remote instruction because of its qualities as a discipline that, according to the Framework for Quality K-12 Engineering Education proposed by Moore and colleagues (2014), should involve design processes, teamwork, and interdisciplinary connections. At the K-12 level, engineering is typically an elective class, which reports suggest were de-emphasized by school administrators in the pandemic so that students could instead focus on core classes (Marshall et al., 2020; Reich et al., 2020). However, a review of two decades of research indicates that engineering education is an effective tool for building students' science knowledge, as well as 21st century skills, such as teamwork and collaboration (Sneider & Ravel, 2021). Thus, engineering education can play an important role in supporting student learning and engagement in the pandemic. In a book compiled in preparation for the 2020–2021 school year, scholars share several opportunities that engineering educators can leverage while teaching remotely, including using asynchronous instruction to differentiate instruction and facilitate student autonomy, using online tools to foster collaboration, and allowing students to draw on their home environments as inspiration for real-world problem solving (Dibner et al., 2020).

STEAM (science, technology, engineering, arts, and math) education is a natural fit within pre-college engineering classes because of its problem- or inquiry-based, collaborative projects that emphasize interdisciplinary connections (Bequette & Bequette, 2015; Lee & Chang, 2017; Perignat & Katz-Buonincontro, 2019; Stroud & Baines, 2019). STEAM has been championed as a successful tool for student engagement and collaboration, making it a possible lifeline for educators faced with low student engagement and isolated learning environments during pandemic instruction. However, transitioning STEAM projects to virtual or hybrid formats posed challenges for educators. Pandemic instruction is perhaps the ultimate test of the successes and challenges of using STEAM as a tool for deepening engagement in engineering contexts.

In this study, we explore both the challenges and possibilities of STEAM instruction within K-12 engineering education in a pandemic through the experiences of three high-school educators, two engineering teachers and their principal, as they navigated hybrid instruction during the 2020–2021 school year. It is crucial to understand approaches for providing engaging, collaborative, hands-on lessons in virtual or hybrid formats, as well as strategies for supporting educators who continue to face pandemic-related challenges with student engagement and changes to the schooling environment. We share the experiences and insights of those most closely involved in teaching pre-college engineering during the pandemic in the hopes that this will shed light on how to better prepare and support teachers and administrators in the future. Using narrative methods, we explored the following research question: What were the lived experiences of two teachers and one administrator during the 2020–2021 school year while delivering engineering and STEAM content to students at a STEM-focused high school during the Covid-19 pandemic?

Background Literature

STEAM in Engineering Education

Over the last decade, STEAM has become an increasingly common acronym within education, though understandings of STEAM vary, reflecting different perspectives on the purpose of STEAM education, pedagogical strategies for investigation, the approach for integrating disciplines within STEAM, and the prominence of the arts or arts integration (Lee & Chang, 2017; Perignat & Katz-Buonincontro, 2019; Stroud & Baines, 2019). The Kennedy Center (2022) defines arts integration as "an approach to teaching in which students construct and demonstrate understanding through an art form. Students engage in a creative process which connects an art form and other subject area and meets evolving objectives in both." This definition is at the center of our understanding of STEAM within the context of this study, which we define as an instructional approach "utilizing student-centered instructional pedagogies, including project-based or inquiry learning, group learning, and real-world application to increase cross-disciplinary content knowledge through learning goals for students in both STEM and arts disciplines" (Boice et al., 2021 p. 5). Engineering is nicely aligned with this definition of STEAM because of the cycles of inquiry and problem solving inherent in the engineering design process (EDP) and the alignment of the EDP with the arts and studio habits of mind (Bequette & Bequette, 2015; Brophy et al., 2008). The EDP also emphasizes the creation of a tangible product, which provides the opportunity for students to demonstrate their learning through an art form, rather than strictly through written reports and tests.

Connections between STEAM and engineering have been documented across K-12 grade levels. For example, a study of three STEAM modules implemented in high-school engineering classes highlights the use of the EDP and cross-disciplinary learning as students produced the Japanese art form origami. More than half of the participating students indicated that the modules reflected multiple disciplines, including arts, engineering, and math, and a majority of students reported an increased interest in engineering (Kennedy et al., 2016). Middle- and high-school students participating in a summer camp

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noticed a similar alignment of engineering and the arts while working on a STEAM activity in which they designed a load-bearing bridge that was then 3D-printed and tested (Oner et al., 2016). Students recognized the need for creativity to design "*abstract*" structures and described the use of 3D-printing their bridge designs to "*express yourself through artistic means*" (Oner et al., 2016, p. 10). At the elementary level, teachers have used design thinking, an approach commonly applied to engineering projects, to maximize exploration and creativity during STEAM activities (Gross & Gross, 2016). In these activities, students explored various materials, musical concepts, and circuitry as they designed and created their own musical instruments, using design thinking to iterate through various versions of their instrument designs (Gross & Gross, 2016).

STEAM in the Pandemic

Findings of a growing, but still limited, body of research on STEAM in the Covid pandemic suggest that K-12 teachers implementing remote STEAM units face new constraints, such as students' access to materials at home and challenges in coordinating collaborative work groups, as well as new possibilities, such as opportunities for family engagement in STEAM projects and the use of readily available technologies to engage students, like WhatsApp or YouTube (Hahn & Carvalho, 2022; Priyantini et al., 2021; Thuy & Ly, 2021; Tsolakis et al., 2022). Indeed, a study of a STEAM robotics project implemented at a high school in Greece found that some technologies, namely Arduino, lend themselves to hybrid instruction, allowing students to begin project work online and easily finish in person as Covid restrictions were eased (Tsolakis et al., 2022). A study of Indonesian elementary-school students participating in a STEAM unit demonstrated that collaboration during remote STEAM units can be challenging, with teachers needing to consider students' access to technology at certain times of day when assigning groups (Priyantini et al., 2021). Additionally, the successful implementation of this remote STEAM project required a high level of parent involvement, as parents were responsible for picking up materials at the school, helping the students complete the project, and troubleshooting technical issues (Priyantini et al., 2021).

Some studies have demonstrated positive outcomes of online STEAM projects. For example, in a study of middle-school students in Portugal, students reported enjoying the opportunity for artistic expression through online STEAM projects. Furthermore, researchers observed students demonstrate critical thinking, creativity, and collaboration between students and their family members while they completed online STEAM projects (Hahn & Carvalho, 2022). A study of high-school students in Indonesia provides support for the successful use of remote STEAM lessons for teaching science content related to ecology (Sigit et al., 2022). Participating students were split into two groups, one of which received an online lesson and the other of which received an online, project-based STEAM lesson integrating technology, art, and science through computer animation. Students who participated in the STEAM lesson outperformed those who received the regular lesson in their mastery of ecology concepts (Sigit et al., 2022). While these studies do not highlight STEAM in engineering courses specifically, they do offer insight into the challenges and successes of implementing STEAM units in remote learning environments. Our study contributes to the literature on implementing STEAM, specifically in high-school engineering contexts, in virtual or hybrid formats.

Engineering Educators' Experiences During the Pandemic

Research suggests that educators experienced personal and professional challenges providing virtual instruction during the pandemic, including low student engagement, technology issues, and balancing teaching responsibilities and personal responsibilities while working from home (Kraft et al., 2020; Marshall et al., 2020). These challenges took a psychological toll on teachers (for a review, see Ozamiz-Etxebarria et al., 2021), though teachers described experiences that mitigated these challenges, including collaborative work environments and school leadership that supported teachers' autonomy (Collie, 2021; Kraft et al., 2020). While there are few studies that specifically describe the experiences of high-school engineering teachers in the pandemic, both college-level and high-school-level engineering educators have noted challenges specifically related to transitioning hands-on engineering coursework to a virtual format (Deters et al., 2020; Park et al., 2020; Reid & Griesinger, 2021). One study of nine high-school teachers piloting a project-based engineering curriculum in the 2020–2021 school year revealed that the teachers were able to complete only some of the online units of the engineering curriculum, citing challenges with student engagement in virtual classes, motivating students to complete work, and student access to technology (Reid & Griesinger, 2021). Instead, these teachers adapted the engineering curriculum to implement small lessons and projects with their virtual students, suggesting that these teachers still saw value in providing engineering opportunities to students, even if only in small doses. Given the paucity of research examining the experiences of K-12 engineering educators during the pandemic, this study aims to gather rich, qualitative data on the experiences of high-school engineering teachers as they provided hybrid instruction.

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Administrators' Experiences During the Pandemic

School administrators played a crucial role in supporting teachers through the pandemic, a crisis that warranted a different skill set from that of leadership during "normal" times and for which many principals were not prepared (Grissom & Condon, 2021; Smith & Riley, 2012). At the start of the pandemic, scholars shared evidence-based strategies for administrators on how to support their teachers through the pandemic, encouraging leaders to promote teacher autonomy, listen to teachers' needs, seek feedback on school-wide decisions, and foster trusting, collaborative relationships with staff (Collie & Martin, 2020; Harris & Jones, 2020). In addition, school administrators were encouraged to practice self-care in response to the emotional toll of supporting their teachers, students, and school communities (Allen et al., 2020; Harris & Jones, 2020). Understanding the experiences of school leaders during the pandemic is important given the unique demands placed on administrators during this time, subsequent mental health impacts, and the influence of administrators on their teachers' experiences and practices. This is especially important in the context of elective courses, like engineering, because school administrators set the priorities for core and elective teachers in supporting students and preventing learning loss. Given the research presented above on the interconnected nature of teacher and administrator experiences, we have chosen to include administrator and teacher perspectives in this study. This provides more context for understanding administrators' experiences, particularly as it relates to their work supporting elective engineering coursework.

Theoretical Framework

This work is situated within a post-positivist qualitative paradigm of research. We used qualitative narrative methods as the theoretical framework for the research design and analysis of findings. Narrative methods allow scholars to "keep a story intact by theorizing from the case rather than from component themes categories across cases" (Riessman, 2008, p. 53). This brings cohesion to the unique experiences of each participant, while recognizing the peculiarities of their context (Riessman, 2008). Each participant's data was preserved as the unit of analysis, which yielded a narrative for each participant in the study. In doing so, we aim to present the teachers' narratives in such a way to build insight for future study of teaching practice during times of crisis.

Methodology

Setting

This qualitative study focused on the experiences of three educators working at a public, suburban high school during the 2020–2021 school year. The school, hereafter called STEM High School (SHS), is located near a major metropolitan city in the southern United States and is part of a large, diverse school district of over 200,000 students and staff. SHS was founded in 2018 and remains the only STEM-focused high school in the district. Families who live in the surrounding area can choose for their children to attend SHS instead of the local high school. Compared to this neighboring school of almost 3,000 students, the student body at SHS is small, made up of only 1,100 students of racially and ethnically diverse backgrounds (48% Hispanic, 24% Black, 16% White, 10% Asian, and 3% Multiracial). At SHS, approximately 60% of students receive free or reduced lunch, which is the same at the neighboring high school (Georgia Department of Education, 2022).

The SHS curriculum emphasizes project-based learning (PBL) and design thinking throughout its classes and offers multiple pathways for students to tailor their education to particular industries, such as engineering and robotics or communication, art, and design. In addition, students can complete certificate programs, Advanced Placement (AP) coursework or the AP Capstone program, and senior internships. Prior to the pandemic, the school offered digital learning days every Friday, during which students completed assignments online and could meet with teachers for additional support but did not attend classes and were not required to report to the school building. Thus, students were accustomed to virtual learning experiences prior to the pandemic. Beginning in March 2020, SHS, along with the rest of the district, finished the school year in a virtual format. The following school year students were given the option to attend school in person or virtually, with teachers providing hybrid instruction, teaching in-person and virtual students concurrently. During this time, SHS continued their pre-pandemic practice of digital learning for all students on Fridays.

STEAM Project Description

The teachers in this study had previous experience and training with STEAM education through their participation in a STEAM professional learning program, GoSTEAM@Tech, administered by Georgia Institute of Technology. As part of this program, teachers work collaboratively during the summer to design projects that integrate engineering and computer science with the arts (including theater arts, media arts, music, and fine arts) and receive ongoing pedagogical and material support during the school year (for more information, see Boice et al., 2021; Rao et al., 2021). In the summer of 2020, the SHS teachers participating in GoSTEAM@Tech collaborated virtually to design a hybrid STEAM PBL unit culminating in an in-person stage production. The teachers designed the unit to emphasize student-centered, project-based, collaborative work in which students created an art piece that could be shared with the school and local community. The unit involved interdisciplinary connections between engineering, technical fields, and the arts and included students enrolled in dance classes; audio, visual, technology and film (AVTF) classes; and engineering classes. Dance students acted in the play, designed costumes, and provided stage management and crew support during the production. Both in-person and virtual students in AVTF classes and engineering classes learned about the goals and needs of theater arts and provided engineering support through set design and construction, as well as sound and audio engineering. Engineering students engaged in the design thinking process as they worked on the STEAM PBL while learning engineering content emphasized through the design and building of set pieces, audio engineering, and visual effects. In addition to supporting the stage production, the AVTF students created a 15-minute video documentary chronicling students' preparations for the performance.

In this paper, we describe the experiences of the two teachers contributing to the STEAM PBL by providing engineering content and support, as well as the experience of their administrator, as all three made decisions and adjustments necessary to provide pre-college engineering instruction and implement a STEAM PBL in a hybrid instructional format.

Participants

This study focused on the experiences of three educators, namely two teachers (Barry and Sidney) and one administrator (Quinn; all names have been replaced by pseudonyms). Barry and Sidney are both veteran teachers, with more than 13 and 9 years of teaching experience, respectively. Both teachers began working in the Career and Technical Education department at SHS three years prior, with Sidney teaching introduction to engineering and mechatronics courses and Barry teaching AVTF courses. While AVTF may not be considered a traditional engineering course, it included content related to sound engineering and engineering technologies. Before taking a position as the principal at SHS, Quinn worked as a district-level administrator for six years and as a high-school science teacher within the district. He entered the principal role when the school was founded, bringing with him 15 years of educational experience and a PhD in a STEM field.

Teachers at SHS began participating in GoSTEAM@Tech in 2019. The 2020–2021 school year marked Sidney's second year of participation in GoSTEAM@Tech and Barry's first year. Both teachers worked closely with the school's dance teacher during the summer of 2020 to design the STEAM projects described in this paper. For the purpose of this paper, we focused on the teachers involved in engineering aspects of the STEAM project (Barry and Sidney) and their principal. As principal, Quinn actively supported teachers' participation in GoSTEAM@Tech and was familiar with both the requirements of the program and the additional support teachers received through their participation in the program.

Interview Methods

In the summer of 2021, each participant completed one 30- to 60-minute semi-structured interview with one of two members of the research team. The interviews were conducted online and were recorded for later transcription. Two interview protocols (provided in Appendices A and B) were developed with questions tailored to the role of teacher or administrator. The protocols included mostly open-ended questions and were used as a guide to elicit responses that would prompt reflective insight into the experiences of the participant (Roulston, 2010). Participants were asked questions about their experiences related to returning to in-person schooling, district and school Covid-19 policies, instructional models of delivering engineering content and implementing STEAM units, and plans to address student learning needs moving forward. The participants and researchers were familiar with each other prior to this study through their involvement in the GoSTEAM@Tech program. Additionally, two of the participants in the study also share authorship of the paper. This shared involvement resulted in a shared understanding of STEAM, which facilitated data collection and analysis.

Data Analysis

The data were analyzed using an inductive and narrative method approach. Two rounds of inductive thematic coding were conducted in which each transcribed interview was coded to classify and categorize data (Saldaña, 2021). Content thematic analysis methods were used to develop the findings (Grbich, 2013). After the first round of initial inductive content coding using NVivo software, two members of the research team met to discuss their observations from the data of each of the participants, concurrent with the coding and content thematic analysis. This meeting resulted in the creation of a series of categories of codes and notes for each interview transcript, indicating a general sense of what each of the participants was describing during the interview. The coders reached consensus and reviewed one another's coding files to reach agreement about the interpretation of the data. The meeting between the coders helped to identify potential blind spots or areas of potential bias towards the topic. Following the meeting, the researchers identified how codes were related to one another, and this informed the second round of coding and ongoing analysis.

In the second round of coding, both researchers coded the interviews that they had not coded during the previous round of coding. Thus, each interview was coded by both researchers and the results of these rounds of coding were discussed in detail to come to a consensus around the narrative themes each researcher was observing in the data. Data chunks, or samples of the coding elements and subsequent analysis, are included in Appendix C to further illustrate the analysis process. To maintain trustworthiness, the narratives were member-checked with participants, two of whom also contributed to the paper. Thus, Barry and Sidney share authorship of this paper because of their contributions to the study involving their narratives and implementation of the STEAM unit described. This situated perspective provides key insight into the topic of study and centers educator experiences and reflections.

Findings

Findings are presented for each participant, beginning with the two classroom teachers followed by the principal, to preserve the participants' unique narrative. Themes that emerged within each narrative are highlighted.

Sidney

How to Be Hands-On and Hybrid

In reflecting on the 2020–2021 school year, Sidney began by describing the initial instructional challenge of teaching engineering content and processes in a hybrid format. The challenge was daunting, as Sydney stated, "especially with a class that is as hands-on as mine. How am I going to do hands-on things with kids that are at home?" However, there were certain aspects of engineering that Sidney felt were "core to what we do as engineers," including engineering design, problem solving, and design thinking, and he began to think creatively about how to expose his virtual students to these aspects of engineering. Sidney developed lessons that required simple materials that might be available to students at home. For example, the students in one of his classes completed a design thinking project for which they only needed sheets of paper to create paper airplanes that met certain design specifications. Sidney tried to use this approach throughout his courses so that students would not need elaborate materials to create and iterate on designs.

During the spring semester, Sidney's need for creativity continued as he figured out how to engage his in-person and virtual learners in the STEAM unit on creating a stage production. Sidney used design thinking to guide his students through set design and construction according to specifications and the needs of the actors and the students providing audio/visual support for the production in Barry's classes. Although both in-person and virtual students participated in the STEAM unit, Sidney found that some tasks were more conducive to virtual participation than others, and stated "I think a lot of the idea sharing and the prototyping, the early stage of the design thinking process could be done fairly well over Zoom." However, in later stages of the design thinking process, Sidney described a "balancing act" in which he tried to include virtual students in the STEAM unit, but eventually began preparing separate mechatronics lessons for virtual students, while his in-person students continued working on the STEAM unit, prototyping, and building set pieces. This was a hard moment for Sydney, who stated:

> I really wanted to be fair to those kids who chose digital and also be fair to the kids who were in-person. So, I tried to balance that as much as I could. That was easier in the beginning, but it was harder as the year progressed because there were projects that we wanted to do that required you physically being here.

Preserving a "Take and Use" Approach to Pre-College Engineering

Sidney's experiences teaching engineering and implementing a STEAM unit in a hybrid format prompted him to revisit core engineering experiences in his own life and his philosophies around engineering education. Sidney described his experiences in college engineering courses as "focused on theory, and that's your ability to solve problems, not necessarily do stuff hands-on." Because the virtual learning environment of some of his students challenged his ability to provide hands-on engineering activities, he noticed "a pull back to the theoretical" in the way he and his colleagues taught engineering during the pandemic. For example, he described how this shift resulted in an increased emphasis on certain parts of his engineering curriculum:

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> So, we can't teach them necessarily the equipment that we have here, or we can't teach them about more specific things that they would have access to at the school, but we can talk about design thinking, and we can talk about problem solving and how do we go through problem solving.

At the same time, Sidney described a commitment to providing pre-college engineering experiences that differ from the theory-driven college-level engineering courses he remembered:

> This is not like a class where you're just sitting around memorizing facts, but this is a class where you're going to put your knowledge into action. I think that's another thing that at least many of the engineering teachers that I interact with, that's what we all agree on is these classes, our classes should be different than another sit-and-get kind of class. It's going to be a take-and-use kind of class.

Hybrid instruction certainly posed challenges for Sidney as he tried to implement hands-on engineering lessons and a STEAM unit that required certain materials and collaborative construction work. However, Sidney's commitment to a "take-and-use" approach to pre-college engineering education is evident in his attempts to include virtual students in as many stages of the design thinking process as possible. Trying to remain "fair" to virtual and in-person students required Sidney to draw on his own creativity and problem-solving skills, in turn providing students the opportunities to develop these skills.

Barry

Limited Access and Limited Interest

For Barry, hybrid instruction meant big changes in his ability to provide instruction, access to necessary software, and collaborative learning experiences. SHS is equipped with state-of-the-art studios and equipment, and Barry described how he would typically work with students to acclimate them to the equipment, "I've got 38, 28-inch iMacs in my classroom. I've got seven different editing suites. I've got a broadcast studio. I've got all sorts of different cameras. If they're here physically I can break them in groups and differentiate effectively." To give his virtual students some exposure to this equipment, Barry spent the first month of the school year loaning out equipment to students, troubleshooting challenges uploading certain software to the Google Chromebooks issued by the district, and coaching students on how to use personal equipment, like phone cameras, to complete assignments. These changes impacted Barry's ability to teach AVTF and grade assignments:

> If I gave a film assignment and I knew the kid didn't have a camera, they were using their mom's phone and they couldn't edit on a specific piece of software or Premier Pro, which is what we normally edit with, and he was using something free off the internet, I took those things into consideration but I still graded him or her for what they turned in, even though I knew that normally they probably wouldn't get a passing grade but under the circumstances I was a little more flexible.

Prior the pandemic, Barry described how his usual collaborative, project-based learning teaching style helped "the shy ones kind of come around and it's much more of a community." Creating this sense of community and collaboration in a hybrid format was extremely challenging because, as Barry described, "the digital kids, they don't interact with each other. They don't turn their cameras on. They didn't interact with each other. I'm sure they felt extremely isolated. They don't want to speak up." Barry was particularly cognizant of the challenges for his younger students, and stated "it was just frustrating but you're talking about a lot of these kids, 14, 15 years old, they have a hard enough time transitioning from middle school to high school just physically in normal circumstances."

A New Window into Students' Lives

Barry understood some of what was at play in the lives of students and the familial contextual environments that supported or hindered students' experiences during a difficult year. Barry was particularly struck by the stark contrast in his students' experiences, and subsequently in his teaching experience, compared with teacher friends at other schools, "the socioeconomic thing is the most interesting aspect I think that we've discussed because I know that I've got friends who teach at very affluent schools who had challenges but not like the challenges that we had." Specifically, Barry described the "socioeconomic demographic factors" that placed significant burden on families during the pandemic, describing parents who "were working around the clock or were unemployed," families who relocated to different countries for a portion of the school year, and students who lacked a private, quiet space to learn at home. These factors made it difficult for teachers to engage students, but also underscored for Barry the disruption caused by the pandemic for SHS's student population. In response, Barry reflected on how he felt his students should prioritize their time on his coursework compared to their other courses:

> You have to understand, this is an elective. This isn't algebra. This isn't biology. This isn't any of the academic classes. I was really cognizant of that because that's a priority. Those are the classes that they were really spending a lot of time on. I don't need these kids spending four hours a day trying to figure out how to download videos that they shot from their phone to their computer.

Reengaging through STEAM

In the spring semester, more SHS students opted to return to in-person learning and Barry noted that this eased his ability to provide collaborative, project-based learning experiences to his AVTF students. In addition, participating in the STEAM theater production gave his students more opportunities for interaction, which led to higher student engagement:

> They were able to work with the engineering kids, they were able to work with the drama theater kids and not just the kids in my classroom… There were much more higher levels of engagement for [the theater production] just because it was such a big thing and you had so many different kids from different departments working on it. They got to kind of collaborate with a lot of those kids.

The STEAM unit led to innovative ways for Barry's virtual and in-person students to collaborate, namely through their work putting together a documentary film about the production. In-person students used the school's film and audio equipment to capture footage of the engineering students and dance students as they prepared for the production. Barry involved different students at different times so that he could account for the constant "shuffling because kids would come and go and disappear" as they dealt with Covid exposures. As in-person students provided new video footage, one virtual student took on the months-long task of editing the footage and producing the final documentary film.

In addition to the documentary, Barry had students doing sound design and visual effects for the production. The interdisciplinary nature of the STEAM unit meant that the AVTF students were designing solutions in response to the needs of dance and engineering students. For example, the dance teacher asked Barry's students to create a hologram figure of a ghost. Barry described how this led students into a period of design and iteration to create the hologram, "that kind of planted the seed. That created engagement because we were like, 'Oh, we could do this,' and 'We could try this. Why don't we try this?' 'Maybe this'll work.'" Despite the challenges of teaching AVTF in a hybrid format, Barry's participation in the STEAM unit reengaged his students and allowed him to rethink the role of AVTF in interdisciplinary contexts:

> Across the board, because we were doing visual effects, we were doing all of the audio, the sound effects, the sound design, and the documentary, just all of those different elements made it I think a lot more engaging. Usually, we're doing production work. We're shooting a short film or we're shooting interview segments. That's just related to what we do. We're now branching out into the other curriculums, which I think was a big positive.

The pandemic gave Barry a closer look into the lives of his students and the competing demands for their time and attention. Barry responded with a flexibility in his approach to instruction, grading, collaboration, and a reconsideration of how AVTF can integrate with other curricula. The STEAM unit was a notable highlight for Barry as he witnessed the way sound design, visual effects, and film could be combined with other disciplines and how this brought a new sense of engagement to his in-person and virtual learners. Even though Barry indicated that his elective course should not be a priority for students balancing personal and academic demands, it is apparent that his class provided students with an important opportunity to engage in collaborative, hands-on projects that reenergized them, and Barry, in the process.

Quinn

Leading Collaboratively in a Crisis

Quinn's collaborative leadership style provided teachers the opportunity to voice their concerns and contribute to the decision-making processes, and it gave teachers the autonomy to make instructional changes as needed. Along with expectations set by the school district, Quinn knew his decisions related to the pandemic would have wide influence across

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the school. Recognizing this, he actively sought input from teachers in the school, allowing them to vote on issues like logistical changes to the class bell schedules, the use of block scheduling to reduce transitions between classes, and social distancing measures in school. Quinn acknowledged that the unique context of SHS meant fewer options for some decisions, like choosing the instructional delivery format for the coming year, and stated "as a small school, some of the district proposed solutions weren't viable. Engineering is a great example. We had one engineering teacher, so we couldn't have a digital engineering teacher and an in-person engineering teacher." Quinn described the result of a summer meeting with teachers in which he and school staff agreed "that teachers were going to teach concurrently, as it became to be known… This turned out, as the year went on, to be one of the most difficult things we've ever tried to do, any teacher, anywhere, for a variety of reasons." However, Quinn also noted benefits this afforded, like continuity in learning because "when a student was out, because they were sick or for any reason, they could just get on to the online class. It allowed students to have the same teacher and for collaboration between in-person and digital."

Throughout the school year, Quinn continued a collaborative leadership approach and involved teachers in problem solving. This sparked conversations about strategies that teachers found effective for engaging online students. Additionally, he described flexibility in his expectations for teachers' completion of at least one PBL unit per semester. Quinn relied on teachers to communicate what was happening as they worked towards completing their PBL units and stated, "I wanted them to be honest with me about what they wanted to do, needed to do. I wanted them to tell me how I could support them. Just really wanted to focus on that goal and that purpose."

Quinn recognized the amount of trust this required and credited his efforts to cultivate that trust with his teachers throughout his tenure at SHS. The "dialogue back and forth" when problem solving was an important trust-building exercise because, as Quinn described, "they [the teachers] realized every time they brought you a problem, you weren't going to immediately fix it and solve it for them, or reprimand them for even coming to you." The importance of this practice was paramount because, as he stated, "ultimately, the better the teachers feel, the more supported they feel, the more likely they are to do things that are of higher potential yield for kids."

"Shackled by Fairness": Rethinking Equity for Hybrid Learnings

When addressing instructional challenges, such as hybrid teaching, Quinn empowered teachers to adjust instruction and encouraged teachers to try new things. He tried to provide opportunities for teachers "to try, fail, pivot, experiment, do some different things, and find that sweet spot that works for them and the students." In doing so, he encouraged teachers to "prune the curriculum, to be really selective and intentional…to differentiate, to really look at what the in-person students were doing, to be vastly different from what the digital students were doing." However, he knew that this might be troubling for teachers initially:

> One thing I learned a lot about my teachers last year is how they can be sometimes shackled by fairness. They want to do the same thing for groups of kids. Helping them realize that the same is not equitable or equal. Figuring out what's best for this group of students and what's best for this group of students is really what's best practice, best thing to do.

Quinn described the need to understand "how we serve different groups of people" and how the challenges of hybrid teaching reflected a need for an approach centered in equity, rather than fairness or equality. Quinn's emphasis on equity was reinforced in his reflections on the role of schools in supporting students holistically, not just academically:

> There's a lot a school does to create an equitable learning environment. We provide technology for students. We provide food, meals, resources, supplies. There's a lot schools do with social organizations to help meet the needs of our families and our students. When suddenly people weren't coming to school, our ability to meet those needs diminished, and then those needs began to grow and exacerbate, which then made us acutely aware of the needs of people, that these needs are huge, that these needs are small. So now how do we manage our resources to better meet the needs of the students who need us the most?

Choosing Priorities: Deciding the Role of Electives and "Extras"

Pandemic-related disruptions to education sparked concerns over possible learning loss and which disciplines would need to be prioritized to make up those losses. Quinn described how a "temptation" to focus on learning loss jeopardizes elective courses:

> I think the temptation, some people may look at it and go, "Well, okay, let's eliminate the arts. Let's eliminate the extra classes. Let's focus on the core." I think we really have to look at, "Well, what's the goal?" Our goal is to graduate

> students who are ready to go to college, into careers, and into the world. They need more of those real-world experiences. Then we need to figure out how to get them the knowledge, the core knowledge they need, to get to that place. It's really about looking, "Okay, what is it that kids need to learn, moving forward? Let's address those gaps moving forward, instead of looking back and wondering what they missed."

For Quinn, elective courses are the perfect opportunity for students to apply their knowledge to real-world problems. Quinn's support for elective courses was evident in his communication with families during the pandemic. For students in elective courses like engineering "that really benefited from in-person learning," he shared information about the safety measures taken to protect in-person students in these classes. Additionally, he coordinated efforts for families to check out equipment or pick up kits of materials for hands-on projects. As the school year progressed, students were encouraged to come to the building after school hours, for example, "coming in and doing sound and video editing at school, under [Barry's] supervision but not in class." Quinn observed that "when students started to have a more traditional experience, even if that was an activity once a week or something that they were doing that was not just passively on the computer, that student engaged in all their classes more." Part of providing this traditional experience to students was through STEAM PBL units, a strategy that Quinn felt paid off:

> It certainly built climate and culture in the school, when we had these events where our kids are getting some sense of normalcy. They're getting to experience the things in school that we know make a difference. There was affirmation of our work. When you're in STEM or STEAM areas, your work is very production-based… The work is validating, so when we allow our teachers and kids to do that work, it validates the effort that they put in, as a teacher and as a student.

While there was a temptation to make up lost instructional time by reducing focus on electives, such as engineering, Quinn emphasized the need to preserve these aspects of the curriculum. Quinn recognized that teachers will not be able to "fill all the gaps," instead encouraging teachers to focus on "work that's engaging and meaningful." Quinn and the teachers invested in a culture of collaboration and shared a holistic vision of student success, allowing them to adapt elective curricula and PBL units to fit the context of the pandemic year while still valuing elective coursework as an important component of students' high-school experience.

Discussion

Hybrid Teaching in Pre-College Engineering Contexts

From its inception, SHS was designed to provide access to state-of-the-art learning environments for students to complete authentic STEM coursework. In the 2020–2021 school year, teachers quickly pivoted their coursework and activities to accommodate hybrid instruction. This was a significant challenge for both Barry and Sidney. Engaging virtual and in-person students necessitated different approaches, and sometimes different lesson plans. Congruent with other research findings, Barry and Sidney described challenges related to teaching students virtually, including student engagement, accountability, and access to materials and technologies (Larson & Farnsworth, 2020; Marshall et al., 2020; Reich et al., 2020; Reid & Griesinger, 2021). This was compounded by the nature of Barry's and Sidney's courses, which were designed to be hands-on, collaborative, and involve specialized materials and technologies. Student collaboration was difficult in the virtual setting, especially when the students were prototyping and building projects. Due to the nature of the virtual and in-person contexts, there were differences in the student experience, and the participants were aware of this. Initially, the teachers attempted to provide similar experiences for in-person and virtual students, but found this to be extremely challenging and, in some moments, impossible. However, in response to this challenge, they developed innovative and creative alternatives for virtual students.

Barry's and Sidney's ability to navigate hybrid instruction during the pandemic was supported by Quinn, whose emphasis on shared decision making and teacher autonomy proved crucial. Quinn established practices that ensured there were options for students to seek additional support, flexibility for teachers to implement adjustments, and open communication between school and the community. Research has demonstrated that autonomy-supportive leadership during the pandemic is important for supporting teacher wellbeing (Collie et al., 2020). It is clear from Quinn's account of the school year that he made an intentional effort to support teacher autonomy through collaborative and flexible leadership. While Barry and Quinn did not speak directly to the effects of this leadership style, their ability to successfully navigate the challenges of the year is testament to the leeway and support they had during a challenging year.

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Holding Space for Pre-College Engineering and STEAM in a Pandemic

In the high-school setting, specialized courses, such as AVTF and engineering, are often considered electives. Barry expressed a belief that other subjects might take priority as "core classes" over his elective course. While all participants emphasized the academic relevance of engineering and STEAM experiences, Barry expressed an awareness of how certain courses are prioritized by students or administrators depending on their status as a core or elective course, a sentiment documented in other studies involving elective teachers during the pandemic (Marshall et al., 2020; Reich et al., 2020). On the contrary, Quinn recognized the value of elective courses for providing a more authentic and engaging experience for students as they learn to apply knowledge from core disciplines, a belief borne out by research on the impacts of K-12 engineering education (Sneider & Ravel, 2021). Going a step further, Quinn affirmed the need for courses that support student innovation and creativity, specifically mentioning avoiding the "temptation" to minimize elective courses. He viewed Barry's and Sidney's classes as an important component of a holistic educational experience, allowing students to see themselves in the content and relate to it authentically.

Quinn expressed an interest and intent to provide more hands-on experiences through STEAM PBL units that would validate and engage students. Quinn's commitment to elective coursework and STEAM PBL implementation was crucial for Barry's and Sidney's ability to successfully contribute to the spring 2021 STEAM PBL and the resulting theater production. Working on the STEAM PBL, while not without challenges, was a highlight for both teachers, as they noticed interdisciplinary collaboration and increased engagement from students. Barry attributed the increased engagement to the collaborative and interdisciplinary work that the STEAM unit demanded of his students. In addition, Quinn noted the inherent accountability of "production-focused" work within STEAM, in which students' efforts could be seen and affirmed by members of the school and local community. These findings are promising given the previously described challenges with student engagement and isolation that were noted by the participants in this study and earlier studies conducted during the pandemic (Kraft et al., 2020; Marshall et al., 2020; Reid & Griesinger, 2021). In Barry's and Sidney's classrooms, the STEAM unit was an effective tool for reengaging students in the engineering content and processes taught by the teachers.

Limitations

The use of qualitative methods allows for rich description of participants' experiences and the choice of three highly experienced educators involved in supporting and implementing STEAM education in a hybrid environment provides a unique topic of study. However, this study relied solely on interview data to understand participants' perspectives on their experiences during the 2020–2021 school year. Future scholars should consider using multiple data sources to examine further through triangulation.

The existing relationships and collaboration between researchers and participants are a potential limitation of this study, despite the benefits of this relationship for establishing rapport and fostering trust between participants and researchers. We addressed this by providing opportunities for participants to check the assumptions of researchers through member checking during the analysis process. No participants requested changes to or reported misrepresentations of their accounts during this process, and we are confident in the representation of participant experiences as a trustworthy account. Furthermore, two of the participants are authors of this paper. This was important to the research team because of the involvement of these participants in the creation and implementation of the STEAM unit described. To limit opportunities for bias that this invites, these authors were not involved in the analysis of their data, other than when member-checking findings, or drafting the presentation of the findings for this paper. We hope that they provide an in-depth look at unique lived experiences of those involved and provide lessons learned that may be transferable to other school settings and relatable to other educators as they deal with the ongoing teaching challenges caused by the Covid-19 pandemic.

Implications

The findings of this study suggest the importance of trust and shared decision making between school administrators and teachers. For the teachers in the study, it was crucial to be able to work closely with students, while adhering to safety measures. Facilitated by the principal, the administration and the teaching faculty were partners in deciding how they would proceed amid uncertainty due to Covid-19. The trust between the school faculty provided the flexibility to make decisions for how to best implement lessons and complete school projects. This echoes the recommendations of scholars who, at the beginning of the pandemic, encouraged administrators to implement autonomy-supportive leadership by listening to teachers' needs, seeking to understand challenges from teachers' perspectives, and getting teacher input on policy decisions

(Collie & Martin, 2020). The need for continued autonomy-supportive leadership is greater now more than ever as educators cope with the stress of lost instructional time caused by the pandemic, student behavior challenges, and staffing shortages, among other concerns (Pressley, 2021; Steiner et al., 2022).

In the face of these challenges, administrators and teachers may feel pressure to prioritize core subjects over elective courses, a sentiment expressed by elective teachers in the pandemic (Marshall et al., 2020; Reich et al., 2020) and by a teacher in this study. Conversely, the administrator in our study expressed that elective subjects, specifically engineering, contributed to the fabric of the school and to the long-term, holistic success of students. These findings have two implications. First, administrators may need to explicitly state and consistently demonstrate to teachers that they value all subjects, including elective coursework. Second, educators should keep in mind the broader student outcomes supported by elective courses and the avenues for including STEAM as a vehicle for developing content knowledge and 21st century skills in elective courses. The participants in our study reported seeing positive student outcomes because of their participation in STEAM projects within the engineering courses.

The findings of our study highlight the challenges of teaching concurrently in hybrid settings and of implementing hands-on, collaborative STEAM units in a remote format. Though SHS and many other schools in the surrounding region have now returned to in-person instruction, the need for occasional remote teaching continues as Covid cases fluctuate and as schools leverage asynchronous remote instructional days to provide teacher planning days during the school week. Educators will need to continue developing online lessons or providing online work for students for such occasions. The results of our study demonstrate that converting engineering STEAM projects to an online format requires careful consideration of which activities are most suitable to remote work and which are best reserved for work time in the school building. Following the example of Tsolakis and colleagues (2022), future research should explore specific technologies and resources that facilitate the easy transition of projects from online to in-person work. Additional research is also needed on how to support K-12 teachers implementing online STEAM lessons, though we hope that the findings of this study offer some preliminary insights on how STEAM engineering lessons can be successfully adapted for hybrid settings.

Conclusion

The experiences of the participants reflect the many challenges of implementing STEAM and engineering content in a hybrid format during the Covid-19 pandemic. Engineering-focused STEAM projects can be done in a hybrid context but require adequate access to materials, flexible school policies, and pedagogical adaptations to effectively engage virtual students. Some of the hands-on aspects and design processes related to prototyping and building were impacted in the virtual space, but the teachers in this study adapted their practice to attempt to provide authentic and engaging experiences, implementing high-quality engineering experiences that ultimately supported students to "use a variety of techniques, skills, processes, and tools in their work" (Moore et al., 2014, p. 5). Additionally, from a STEAM perspective, the integration of multiple subjects in the STEAM unit resulted in collaborative, interdisciplinary student work and a successful artistic product that was shared widely within the school and local community. Engineering educators will continue to need professional learning opportunities focused on real-world applications of engineering, curriculum implementation support, and collaboration with other teachers and experts (Mesutoglu & Baran, 2021). These professional learning opportunities should include practices, with STEAM among them, for engaging students in a virtual or hybrid setting as schools continue occasional virtual learning in response to fluctuations in the Covid-19 pandemic.

School leadership in this study played a key role in setting expectations, establishing trust among colleagues, and addressing challenges within and beyond school walls. By including the perspectives of both the teachers and their administrator, we see differing views of the challenges and successes of the school year, as well as the alignment between supportive administration and the possibilities for teacher creativity, autonomy, and perseverance in a challenging year. The resources and policies leveraged to support the wellbeing of teachers and their students in this study were apparent. Future studies should continue to explore how interactions between administrators and teachers can promote wellbeing throughout the school community as education faces increasing reports of teacher burnout and emotional exhaustion (Pressley, 2021; Steiner et al., 2022).

The Covid-19 pandemic will have lasting impacts on the field of education. This study contributes to our collective understanding of the disparate effects of the pandemic on certain groups of students, teachers, and disciplines. As we move through the wake of virtual pandemic instruction, it is imperative to continue understanding how to promote equitable educational experiences and explore the important role of pre-college engineering in engaging students in hands-on, authentic learning experiences.

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Author Bios

Justina R. Jackson is a Research Scientist II at the Center for Education Integrating Science, Mathematics, and Computing (CEISMC) at the Georgia Institute of Technology. She is a qualitative methodologist specializing in critical theories in education.

Katherine L. Boice is a Research Associate II at CEISMC at the Georgia Institute of Technology. At CEISMC she contributes her knowledge of child developmental and research methodologies to various projects and evaluations.

Stephen Cochran is a STEAM K-12 Teacher and School District Partner for GoSTEAM@Tech.

Brooke Skelton is a STEAM K-12 Teacher and School District Partner for GoSTEAM@Tech.

Jeffrey Rosen is a Program Director at CEISMC at the Georgia Institute of Technology.

Marion Usselman is the Associate Director for Development and Educational Innovation at CEISMC at the Georgia Institute of Technology. Marion relishes developing partnerships with interested STEM/STEAM educators and academics in all fields to help promote STEM/STEAM in K-12 schools.

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Appendix A

Teacher Interview Protocol

1. What was the "return to school" like in fall 2020?
    a. What was communicated to you about the district's "return to school"?
        i. How did this manifest at [school name]?
    b. Were there any school-level policies that you implemented in addition to district-level Covid policies?
        i. Any CTAE/engineering specific policies?
        ii. What policies/procedures changed for grading/student accountability (e.g., switch to pass/fail, limits on assignments)? Any school/district policies about the expectation for student work submission to pass course?
        iii. How did these policies/practices influence your engineering classes (e.g., changes in mastery expectations for content, # of assignments required, etc.)?
    c. What were you told about how you should be "doing" engineering education during the pandemic?
    d. Were there any changes made to your school/class schedule that impacted how you taught engineering (e.g., length of class time, # of students taught per class, etc.)?
    e. How did the communication change between you and students/families? What did you tell families they could expect from your classes?
2. Please describe the classes in which you implemented your GoSTEAM@Tech activities during the 2020–21 school year.
    a. Which classes or parts of courses were associated with the planned activities [part of program]?
    b. What percent of students in these classes were virtual vs. F2F? Did they change over the course of the year?
    c. Subject, grade level, type of student (AP, general, intro, etc.), length of course
    d. Did you use your STEAM PBL as an instructional model or an enhancement?
    e. What changes were made to the classes to meet the needs of students?
    f. When you were working on the GoSTEAM@Tech activity, was that the only thing students were working on? Was this layered on top of other ongoing curricula?
3. What sorts of activities did you do in the project this year to help teach engineering skills or content (e.g., mostly hands-on, lecture based, flipped classroom, group work, etc.)?
    a. Was this different from how you've taught the same skills/content in the past (before Covid)? How did you adapt engineering instruction in response to pandemic?
    b. Did you face any new or unexpected challenges teaching engineering through activities because of the pandemic?
4. What was the student engagement like during activities? How did you interact with students? (teachers)
    a. How did engagement during activities differ from engagement during other parts of classes or in general?
    b. Did engagement levels differ for F2F vs. virtual students?
    c. Did you make any changes to the assignments or activities involved in to increase student engagement last year?
5. What are the anticipated gaps in engineering skills/knowledge for students to address next year?
    a. Do you think this will vary depending on what instructional mode students participated in last year?
    b. What kinds of support are you receiving/will you receive from the administration and district?
6. What other information would you like to share about your experience teaching engineering during the pandemic?

Appendix B

Administrator Interview Protocol

1. What was the "return to school" like in fall 2020?
   a. What was communicated to you about the district's "return to school"?
      i. How did this manifest at [school name]?
      ii. What policies/procedures changed for grading/student accountability (e.g., switch to pass/fail, limits on assignments)? Any school/district policies about the expectation for student work submission to pass course?
   b. In addition to district-level Covid policies, were there any school-level policies that you implemented in response to the pandemic?
      i. Any CTAE/engineering specific policies?
      ii. How did you communicate changes and policies with teachers?
      iii. How did you communicate the expectations for the school year to students and families?
      iv. As families were deciding whether to attend virtually or F2F, what were they told they could expect from each format?
   c. How did communication change between you and teachers this year, if at all?
   In this section, we'll ask questions about the GoSTEAM@Tech program in particular.
2. What were your expectations for your school's involvement in the GoSTEAM@Tech program during the 2020–21 school year?
   a. Were there any changes you had to make to accommodate GoSTEAM@Tech in the engineering classes because of the pandemic or virtual/hybrid instruction?
3. What did you or fellow administrators notice about student engagement during these observations?
4. In thinking about CTAE and engineering classes moving forward, what are the anticipated gaps in skills/knowledge for students to address next year?
   a. Did this vary depending on what instructional mode students participated in?
   b. What kinds of support are you receiving from the district?
   c. Are there plans for school-level policies that will help close any gaps in the coming year?
   d. Overall, do you think the pandemic has had an impact on engineering education at your school?

Appendix C

Table 1
Illustrative narrative data chunks.

Coding elements	Sidney data excerpt
Concurrent teaching stress	And then we arrived the first day and every class is mixed, every class has digital and in-person at the same time. And so, there were all these stresses about how are you going to do that? And especially with a class that is as hands-on as mine, how am I going to do hands-on things with kids that are at home?
Adjustments to design thinking	One of the things I wanted to teach in my class is design thinking. So how are they going to do the design thinking process of going through of finding a problem and then dealing with that problem, and then ideate and iterations on your design… And so there was a lot of what can we do with students that is engineering, mechatronics type stuff, but does not require a lot of new materials or specialized materials that the kids probably can find at home.
Opportunity	So, it was really just an opportunity to get creative and think about things in a different way. And if I were at home, what kind of materials would I have available to engineer something?
Balance and fairness in instruction	But there was a delicate balance, because I really wanted to be fair to those kids who chose digital and also be fair to the kids who were in-person. So, I tried to balance that as much as I could. That was easier in the beginning, but it was harder as the year progressed because there were projects that we wanted to do that required you physically being here.
Student collaboration experience	But yeah, it was hard, because you wanted kids to prototype, and so the kids at school had some resources that kids at home didn't have. But yeah, that was a balancing act of trying to make sure that the kids are getting a very similar experience. It wasn't the same experience, but I was trying to give them a similar experience.
Limitations of hybrid instruction related to prototyping	So, there were some limitations, but I think a lot of the idea sharing and the prototyping, the early stage of the design thinking process could be done fairly well over Zoom… There's a certain level of collaboration you can have, but it's not going to be necessarily the depth that you would have if you were in person. But I would say in that way it was successful and it met my expectations, but just not being able to follow through to the end was a challenge.
Limits of hybrid instruction	So again, that was kind of the brainstorming, the prototyping, the idea phase. That could all be handled collaboratively online, digitally through Zoom and stuff like that. But there did reach a point where it's like, you know what? I'm sorry, guys. You're going to be doing different lessons because there's no way… We actually have to build stuff. There's a play coming and you're getting a different lesson. At that point we have the split.
Personal experiences comparing engineering education	Having gone through engineering education myself, I would say in general, especially college engineering, is focused on theory. And that's your ability to solve problems. Not necessarily do stuff hands-on. And I feel like in high school, it's much more of a hands-on experience. So, I'm doing way more hands-on stuff than I ever did in my engineering classes.
Application of pre-college engineering	This is where you actually build stuff, this is where you make things. It's where you see physics principles in action, you use things that you've learned in other classes to do stuff.
Pull back to the theoretical	I would say there was a shift. It's like, how are we going to do all this? We were all asking this question. We would go to meetings, and it'd be like, "what are you guys doing? Because we're trying to do hands-on stuff, but how, how are you getting your kids to do anything hands-on when they're at home and don't have that access to the materials that you have at the school"… I think it was maybe more of a pull back to theoretical.
Possibilities of design principles	And I would say engineering design, problem solving, design thinking, these are all things that are core to what we do as engineers. And so, I think a lot of us were like, "Okay, that's something that we can teach at home with the materials that they have."
Possibilities and limits of design principles	So, we can't teach them necessarily the equipment that we have here, or we can't teach them about more specific things that they would have access to at the school, but we can talk about design thinking, and we can talk about problem solving and how do we go through problem solving. So, I think it was a shift from curriculum focus to more like, "Let's focus on problem solving, because that is something we can talk about at home and designing solutions for maybe problems you got going on at home." There were ways to teach that, but maybe just less specific.
Application of engineering classes	This is not like a class where you're just sitting around memorizing facts, but this is a class where you're going to put your knowledge into action. I think that's another thing that at least many of the engineering teachers that I interact with, that's what we all agree on is these classes, our classes should be different than another sit and get kind of class. It's going to be take and use kind of class.

Table 2
Illustrative narrative data chunks.

Coding elements	Barry data excerpt
Content area teaching	I teach AVTF is what we call it, audio, video, technology, and film. I teach one, two, three and four. They're [year one and two] learning all the tools and all the different software and cameras and hardware and all that. Then year three and four they're just producing. I'll still introduce new content to them but a large part of classes three and four is just production.
Flexibility in grading	If I gave a film assignment and I knew the kid didn't have a camera, they were using their mom's phone and they couldn't edit on a specific piece of software or Premier Pro, which is what we normally edit with, and he was using something free off the internet, I took those things into consideration but I still graded him or her for what they turned in, even though I knew that normally they probably wouldn't get a passing grade but under the circumstances I was a little more flexible.
Student assignments	For the theater production, I was doing sound design. I had some kids working on sound design. I had kids doing the documentary and then I had kids doing the visual effects. I had more kids, but my responsibilities were a lot larger on [theater production] than they were on the podcast.
Example of student assignment	The editor [virtual student], she edited everything, but we were producing the play for, I don't know, three months at least, three and a half months. We were constantly shooting behind-the-scenes footage throughout those three months. I probably had 10 or 12 kids doing that on and off.
Challenge of student assignments during pandemic	I was constantly just shuffling because kids would come and go and disappear. A kid would be in close contact, and they would disappear for two weeks… This happened in all my classes on all my different projects. We'd be in the middle of producing something and all of the sudden so-and-so's out for two weeks because his brother tested positive for COVID or whatever.
Hybrid/virtual instruction	Obviously, I had to teach the virtual students a lot different. I was making videos [inaudible]. I didn't have them in front of me and have my hands on the camera and showing them different things. Yeah. A lot of things changed. Not so much in person but digital, I had to revamp everything. I made a lot of video tutorials. I did a lot of one-on-one sessions. A lot of my kids were freshmen. You put a freshman in front of a computer all day and expect them to do work that they don't understand, after a couple days a lot of them just zone out. They won't even turn their camera on. You can't even get a response. They'll just log in and then you don't even know. You're just talking to a blank computer screen. That was a huge problem.
Socioeconomic factors for virtual students	It was just frustrating but you're talking about a lot of these kids, 14, 15 years old, they have a hard enough time transitioning from middle school to high school just physically in normal circumstances. From the demographics that we teach, just the socioeconomic demographic, their parents weren't there, or a lot of their parents were working around the clock or were unemployed and you had all kind of brothers and sisters and aunts and uncles in the same room, same apartment with two or three computers.
Learning environments for virtual students	Most of them don't have good internet connections. They're in a room. They're usually sharing a room, whether it's with a sibling or parent. They're hesitant to turn their camera on or they're hesitant to say anything because as soon as they turn their mic on, you hear all this other noise.
Virtual student interaction	Of course, the digital kids, they don't interact with each other. They don't turn their cameras on. They didn't interact with each other. I'm sure they felt extremely isolated. They don't want to speak up. When you're physically in person, there's just a social element that is conducive to learning when they're all physically there and mingling and you put them in groups and, yeah, you may have a couple shy kids but especially in a class like mine when you're doing fun stuff like filming stuff, eventually the shy one's kind of come around and it's much more of a community. That didn't happen when you're digital to these kids.
Technological needs for assignments	The majority of my students checked out Chromebooks and a Chromebook won't run any of the Adobe suites, so I had to find another editing software program for them… It would work for a few of them. A lot of them, no, that didn't work. If they have Chromebooks, it's not possible to download videos to a Chromebook.
Technological needs for assignments	I had to take that into consideration when they were making videos. I checked a lot of cameras out to my upper-level kids. I've got 18 nice DSLRs. I've got Canon T7i Rebels and Canon Handheld camcorders. First of all, I encouraged the kids to use their phones. If you have a good phone, good camera, you're going to use that. If you don't, I'm going to give you a camera.
Adjusting expectations based on technological limits	All the challenges, at first, I didn't realize it was going to be a big challenge. I was just, "Okay, they have computers. Okay, we can put Adobe on a school computer." A couple days later, "Oh, we don't have enough laptops. They're going to have to go to Chromebooks." Just gradually, as the weeks went on, after about the first month I knew what I was in for. It took about a month to… All the challenges presented themselves after the first month or so. As far as equipment and I was like, "Okay, I can't hold these kids responsible like I normally would if they were in person."

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Table 2
(Continued)

Coding elements	Barry data excerpt
Adjusting expectations compared to academic courses	It got to the point, my level one kids, one project they had to do was a PSA video on a different topic… Just create a short little PSA. As long as they turned anything in. If they just turned literally a three-clip edited video of them interviewing a couple siblings and just put those three clips together on their phone and sent it to me, I would give them a 70 because a lot of times they just wouldn't send anything in… You have to understand, this is an elective. This isn't algebra. This isn't biology. This isn't any of the academic classes. I was really cognizant of that because that's a priority. Those are the classes that they were really spending a lot of time on. I don't need these kids spending four hours a day trying to figure out how to download videos that they shot from their phone to their computer.
Catching up	What we need, or what I need, is just extra time with these kids. I'm going to have to a lot of differentiation, and I always have to do a lot of differentiation in my group because I'm an elective. I'll have ninth graders in the same class as twelfth graders. I'll have kids who have been making films since they were in fifth grade come into my class, being in the same class with somebody who's never touched a camera under normal circumstances so I'm kind of used to that. The amount of volume is going to be greater. I'm going to have just much more of that. I'm used to that but the numbers and the amount of differentiation that I'm going to do is going to be a lot greater, but I was doing it last year.
Conducive and equipped classroom environment	It's [the upcoming year] just going to look different because I'm going to have them all in the classroom. It's going to be easier than it was last year. This year will be easier just because at least they have the tools. At least I can put… Our facility's great. I don't know if you've been to our school, but we have, it's a huge school. I've got 38, 28-inch iMacs in my classroom. I've got seven different editing suites. I've got a broadcast studio. I've got all sorts of different cameras. If they're here physically I can break them in groups and differentiate effectively, much more effectively than I could last year when they weren't all in person.
Reflection on the theater production	They loved it [theater production]. The fact that there was a big picture, this big production, the fact that they were able to work with the engineering kids, they were able to work with the drama theater kids and not just the kids in my classroom. They were able to go up into the sound booth and look at the sound board and how is that going to fit into this huge production that our school's doing? There were much more higher levels of engagement for [theater production] just because it was such a big thing and you had so many different kids from different departments working on it. They got to kind of collaborate with a lot of those kids, especially my kids who were working on the documentary, who go to actually go and shoot footage of the engineering department making all these set pieces. A lot of these kids hadn't been exposed to that.
STEAM integration, student engagement, creativity	The fact that they were able to go in and watch [teacher] teach a drama class and watch these kids practice and all the visual effects that were done in the play. You saw the documentary; we had never done anything like that. The fact that they were able to do something brand new and experiment and put their own stamp on it, because [teacher name] was like, "It would be cool if we could somehow create this kind of ghostly hologram figure to appear and then my kids," that kind of planted the seed. That created engagement because we were like, "Oh, we could do this," and "We could try this. Why don't we try this?", "Maybe this'll work."
STEAM integration success	Across the board, because we were doing visual effects, we were doing all of the audio, the sound effects, the sound design, and the documentary, just all of those different elements made it I think a lot more engaging. Usually, we're doing production work. We're shooting a short film or we're shooting interview segments. That's just related to what we do. We're now branching out into the other curriculums, which I think was a big positive.

Table 3
Illustrative narrative data chunks.

Coding elements	Quinn data excerpt
Collective solutions to address district policies	As a small school, some of the district proposed solutions weren't viable. Engineering is a great example. We had one engineering teacher, so we couldn't have a digital engineering teacher and an in-person engineering teacher.
Contextual viability	We knew right away that some of the things the district was saying were not viable. They were mostly talking about, they're speaking about the vast majority of situations, which is second grade teachers and fourth grade teachers. When you get into high school and highly specialized areas, those generalizations don't hold true.
Coming together to make decisions	So, we brought the staff together. We can't go correct the superintendent's press release, but what can we do to be in compliance with district expectations and meet the needs of our students?
Concurrent teaching	Then the other thing we agreed is that teachers were going to teach concurrently, as it became to be known. They would teach their in-person students and digital students at the same time. This turned out, as the year went on, to be one of the most difficult things we've ever tried to do, any teacher, anywhere, for a variety of reasons. It did also provide some benefits. When a student was out, because they were sick or for any reason, they could just get on to the online class. It allowed students to have the same teacher and for collaboration between in-person and digital.
Teaching and instructional adjustments	I enabled teachers and encouraged teachers to prune the curriculum, to be really selective and intentional. I encouraged teachers to differentiate, to really look at what the in-person students were doing, to be vastly different from what the digital students were doing. Then we talked through about how we would get supplies and resources to our at-home learners.
Virtual and in-person student work	Then also just really began to sit down and talk to the teachers. "Okay, I really want to do this with my in-person kids, but I feel bad about the digital kids." Helping them basically embrace the fact that, "You're going to give the digital student a project that they're going to do digitally. If you want your other kids to build something, create something, do something in person, that's okay." Really encouraging and empowering them.
"Shackled by fairness"	One thing I learned a lot about my teachers last year is how they can be sometimes shackled by fairness. They want to do the same thing for groups of kids. Helping them realize that the same is not equitable or equal. Figuring out what's best for this group of students and what's best for this group of students is really what's best practice, best thing to do.
Reframing equitable experience	I think as teachers, we're rule-followers. We like rules. Fair is something that we try to be. I think as we learn about concepts of equity and equality and fairness, there's different approaches to that work and how we serve different groups of people. Usually, we're thinking about race or special ed or other characteristics. We never really thought about, "Well, this kid is sitting in front of me, and this kid is at home." How that experience maybe can't be the same.
Increased awareness of students needs	There's a lot of school does to create an equitable learning environment. We provide technology for students. We provide food, meals, resources, supplies. There's a lot of schools do with social organizations to help meet the needs of our families and our students. When suddenly people weren't coming to school, our ability to meet those needs diminished, and then those needs began to grow and exacerbate, which then made us acutely aware of the needs of people, that these needs are huge, that these needs are small. So now how do we manage our resources, to better meet the needs of the students who need us the most?
The "temptation" to address learning loss	I think the temptation, some people may look at it and go, "Well, okay, let's eliminate the arts. Let's eliminate the extra classes. Let's focus on the core." I think we really have to look at, "Well, what's the goal?" Our goal is to graduate students who are ready to go to college, into careers, and into the world. They need more of those real-world experiences. Then we need to figure out how to get them the knowledge, the core knowledge they need, to get to that place. It's really about looking, "Okay, what is it that kids need to learn, moving forward? Let's address those gaps moving forward, instead of looking back and wondering what they missed."
STEAM relevance	I think those classes give students an opportunity to apply concepts, academic concepts, and core skills, in ways they don't get to in other classes. If you compare an engineering class to a physics class, in many ways, the ideas, the concepts, the foundational laws of the universe that govern those things, very similar, physics and engineering. However, the way we apply those in an engineering context is, we're solving problems and we're actually trying to produce products and trying to demonstrate that we have professional skills and knowledge that we're accumulating. In a physics class, it's a much more academic experience, where we're trying to determine if Newton was right. In that journey of determining, every time we figure out Newton was, in fact, right. That academic experience, versus that applied experience, resonates much more. I think the applied experience resonates more, with more students, than the academic experience does.

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Table 3
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Coding elements	**Quinn data excerpt**
Teacher and student affirmation	I think it certainly built climate and culture in the school, when we had these events where our kids are getting some sense of normalcy. They're getting to experience the things in school that we know make a difference. There was affirmation of our work. When you're in STEM or STEAM areas, your work is very production-based. It's very product-based. If there's no production or product, did work even happen? The work is validating, so when we allow our teachers and kids to do that work, it validates the effort that they put in, as a teacher and as a student.
STEAM application is meaningful and engaging	Because they're trying to do something that has more real-world application and more meaning to it. I think that's important. It's funny that you talk about meaningful. My two buzzwords for this year are engaging and meaningful, so I'm talking to lots of teachers about, "Can we do work that's engaging and meaningful?" Because if we do that, that turns the flywheel of student work. It gets the student engaged. Once the student is working and applying, our work as educators gets a lot easier. Getting the student to that place, of risk taking and commitment and investment. Once the student invests, our teaching is a lot easier.

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