A School-University Partnership for Integrated STEM Learning: Curriculum Modifications and Considerations for Emergency Remote Teaching

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Abstract: Emergency remote and hybrid instructional approaches during the COVID-19 pandemic presented new challenges to science teachers, including how to incorporate authentic, hands-on, and collaborative learning experiences via Zoom™ instruction. Through a school-university partnership, a first-year middle school science teacher, an assistant professor, and two doctoral students collaborated to support student learning despite the constraints imposed by COVID-19. The partners worked together to develop and adapt a six-lesson, integrated science, technology, engineering, and mathematics (STEM) unit for use in a hybrid learning environment. In this article, we describe the unit, which focused on science concepts of force and motion through an engineering context related to helmet design. We highlight the key adaptations that were made to transition this unit to a hybrid format, including the assets brought by each partner. Finally, we discuss lessons learned and implications for teachers.

KEYWORDS: integrated STEM education, research-practice partnership, emergency remote teaching, COVID-19, teacher professional learning

NAPDS NINE ESSENTIALS ADDRESSED:

Essential 3: A PDS is a context for continuous professional learning and leading for all participants, guided by need and a spirit and practice of inquiry.

Essential 4: A PDS makes a shared commitment to reflective practice, responsive innovation, and generative knowledge.

Essential 5: A PDS is a community that engages in collaborative research and participates in the public sharing of results in a variety of outlets.

Essential 8: A PDS creates space for, advocates for, and supports college/university and P–12 faculty to operate in well-defined, boundary-spanning roles that transcend institutional settings.

Essential 9: A PDS provides dedicated and shared resources and establishes traditions to recognize, enhance, celebrate, and sustain the work of partners and the partnership.

Acknowledgments
This material is based upon work supported by the Toyota USA Foundation. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Toyota USA Foundation.

Introduction

The COVID-19 pandemic brought about unprecedented challenges for K-12 teachers, who suddenly were required to teach remotely and in hybrid (some students remote and some in person) formats, often lacking clear guidance and support. Emergency remote teaching (ERT) is distinct from online and distance learning, which often require months of advance planning; ERT includes a rapid and temporary shift in instructional delivery mode in order to provide short-term access to instruction that would otherwise be unavailable (Hodges et al., 2020). With the shift to ERT, questions about instructional quality and student engagement arose (e.g., Bassok et al., 2021; Phillips et al., 2021). In particular, integrated science, technology, engineering, and mathematics (STEM) instruction often requires access to physical materials for inquiry-based learning and engineering design activities. Challenges associated with providing students STEM learning materials were exacerbated with ERT instruction associated with COVID-19. In order to implement an integrated STEM unit, teachers had to ensure that all students had access to the required materials regardless of whether they were learning at home or in school.

Through a school-university partnership, we sought to provide authentic, hands-on, and collaborative STEM learning experiences to middle school students via ERT, including fully remote and hybrid modalities. We developed an integrated STEM curriculum unit for implementation in a hybrid ERT context, utilizing continuous improvement approaches (Bryk et al., 2015) during the development and implementation of the integrated STEM unit to address the unique challenges associated with teaching during COVID-19. We addressed the following research questions:

1. How, if at all, do the teaching practices of a first-year teacher shift when coaching and integrated STEM curriculum materials are provided during ERT?
2. What unique assets do a first-year teacher and three university partners draw upon in developing and implementing an integrated STEM unit using ERT?
3. What challenges and successes do a first-year teacher face when providing integrated STEM instruction using ERT?

In this article, we will first briefly describe some of the relevant research on reform-based science teaching and research-practice partnerships. We will then describe the research design we utilized and share our findings related to the research questions. In particular, we will unpack the challenges and successes (Research Question 3) to include implications for teachers beyond the context of this study. Finally, we will share a broader discussion of the study, describe some of its limitations, and suggest areas for future research.

Literature Review

Reform-Based Science Teaching

Reform efforts in science instruction have called for student-centered, inquiry-based, hands-on learning experiences that allow students to learn science concepts through the use of science and engineering practices (e.g., National Research Council [NRC], 2012; NGSS Lead States, 2013). Reform-based teaching is grounded in constructivist learning theories; in science, this includes starting with questions about nature, collecting and using evidence, and integrating "knowing" with the process of finding out (NRC, 1996, p. 30). It also includes student collaboration, student discourse, and reflection (Piburn & Sawada, 2000).

However, adopting new instructional practices can create a range of tensions for teachers (Braaten & Sheth, 2017; Radloff & Capobianco, 2021; Windschitl, 2002). They must learn to execute new pedagogical approaches to science instruction, and they must also navigate matters related to teacher accountability measures. In particular, past research has shown that teachers perceive the integration of STEM disciplines to conflict with standardized tests, which often emphasize vocabulary knowledge over conceptual understanding (e.g., Hutner et al., 2022; Marshall et al., 2021). Even beyond integrated STEM instruction, high-stakes accountability testing often leads to a narrowing of the curriculum, with tested topics receiving the most focus (Byrd-Blake et al., 2010; Pinder, 2013). Thus, teachers adopting reform-based science teaching practices are faced with the dual challenges of learning and implementing pedagogical strategies within a system that may not prioritize reform-based approaches.

Research-Practice Partnerships

Research-practice partnerships (RPPs) represent an intentional collaboration among researchers and teachers to support improved instructional practices and educational outcomes. RPPs are a key strategy in providing improved and more equitable STEM education (National Academies of Sciences, Engineering, and Medicine [NASEM], 2021). Coburn and Penuel's (2016) review of studies on RPPs found largely positive student learning outcomes associated with interventions developed by RPPs. In addition, other studies have found that instructional practices improve in connection with RPP interventions (Yarnall et al., 2006). Thus, RPPs provide a rich context for supporting teachers in developing quality STEM instructional approaches, potentially improving student learning opportunities.

Research Design

Context

This project built upon an existing RPP among a mid-sized private university, a large urban school district, a Fortune 100 company, and local community partners in the Southwestern United States. The partners intend to develop a hybrid "third space" that links the K-12 and university settings (Zeichner, 2010). Following three years of co-planning among the four partners, the STEM School opened in August of 2021. Currently serving students in grades 7-8, the school will expand its reach until it serves grades PreK through 8. The school is composed primarily of Latinx (71%) and Black (26%) students. Schools in this area have been characterized by low rates of student achievement compared to other schools in the district, and the community has been fraught with distrust due to school closures and environmental injustices associated with a nearby superfund hazardous waste site. Hundreds of students leave the neighborhood to attend private and charter schools with better records of academic success. With an overarching goal of equity, the

STEM School aims to provide a high-quality education to students in the community while also supporting students' families by providing wraparound services.

Innovation at the STEM School includes teaching approaches and curriculum materials being utilized in the classroom. While schools and teachers in this urban school district have often relied on direct instruction of facts and vocabulary in an effort to prepare students for multiple choice standardized tests, research-based best practices call for deep, conceptual learning by doing (NASEM, 2021; NGSS Lead States, 2013). The STEM School is therefore developing and utilizing science curriculum materials that engage students in inquiry through the use of science and engineering practices. With a marked shift from lecture and memorization, both teachers and students require additional support as they begin to experience open-ended learning activities, such as engineering design challenges.

Participants

The project activities represented in this article included four key individuals. Nick (pseudonym), a first-year middle school science teacher, sought the opportunity to serve as a school-based partner because he wanted to give his students hands-on STEM learning experiences in his science instruction. A university assistant professor and two doctoral students served as the university-based partners, refining integrated STEM unit activities based on Nick's feedback and supporting his planning and reflection throughout the unit implementation. As the only science instructor of this particular subject at his school, Nick expressed a desire for this collaborative planning process.

Curriculum Context

The teacher first taught a district-prescribed chemistry unit. It addressed chemical equations, formulas, and bonds over five 90-minute class periods (see Table 1). The teacher then shifted to the integrated STEM unit, which was developed based on Moore et al.'s (2014) framework for integrated STEM instruction, which includes six key tenets: 1) a motivating and engaging context; 2) an engineering design challenge; 3) opportunities to learn from failure through redesign; 4) inclusion of science and/or mathematics content; 5) student-centered pedagogies; and 6) an emphasis on teamwork and communication. The integrated STEM unit was comprised of six lessons focused on concepts of force and motion and aligned with the state science standards (see Table 2). After agreeing on the topic and engineering design challenge that centered on student design of helmets to meet the needs associated with a specific activity of students' choosing, the university partners drafted initial lessons. The lessons were designed with Nick's particular students and context in mind, so each lesson was designed to be taught in a 90-minute class period. When the initial lesson drafts were completed, they were shared with Nick for his feedback, and additional revisions were made to the plans in the days immediately preceding Nick's implementation of the lesson. Nick was also encouraged to make in-the-moment adjustments he deemed necessary to meet his students' needs.

Table 1
Comparison Unit Lessons

Lesson	Learning Objective	Lesson Details and Activities
1	Students will interpret the periodic table, including groups and periods, to explain how properties are used to classify elements.	Practice standardized test questions Article about covalent bonds Teacher slide presentation on elements and valence electrons Practice questions identifying number of valence electrons
2	Students will recognize the types of elements that are on the periodic table.	Practice questions identifying number of valence electrons Article about metals Teacher slide presentation on periodic table groups and families
3	Students will recognize what the numbers in a chemical formula mean.	Practice questions locating elements on periodic table Article about amino acids and identifying differences between compounds Teacher slide presentation on subscripts and coefficients in chemical equations Practice questions to interpret subscripts and coefficients PhET simulation about chemical equations
4	Students will recognize what the numbers in a chemical formula mean.	Practice questions to interpret subscripts and coefficients Article about hydrogen peroxide and its uses Elephant toothpaste video Teacher slide presentation on numbers in chemical formulas Worksheet with practice counting elements in chemical equations.
5	Students will distinguish between physical and chemical changes and properties of matter.	Video about different elements' reactions to water Teacher slide presentation about physical and chemical changes

In Lesson 1, students were introduced to basic concepts of force, motion, and energy through a melon drop and a bouncy ball lab. They also interacted with guest speakers from the Fortune 100 industry partner to learn about the engineering design process, continuous improvement approaches, and collaboration. Lesson 2 focused on deepening students' understanding of force and motion, including Newton's laws of motion and associated calculations. Students participated in a Google Jamboard™ activity to define key vocabulary terms in everyday language and completed station activities to explore a PhET simulation, practice force and distance calculations, and learn about helmets in the National Football League. Lesson 3 included a discussion and drawing of forces that were present during the melon drop from Lesson 1. The focus then shifted to the helmet design challenge, including an introduction, discussion of criteria and constraints, small group design work, and peer feedback on initial design ideas. Lesson 4 and Lesson 5 were designated for ongoing work on the helmet design project. As part of the design process, students were required to develop a presentation that included a description of their helmet prototype, video footage of the prototype being tested, and relevant force and speed calculations. Lesson 6 provided students with the opportunity to present their designs to a panel of experts, including industry engineering partners, and ask and respond to questions about their designs.

Table 2
Integrated STEM Unit Lessons

Lesson	Learning Objective	Lesson Details and Activities
1	Students will describe the relationship between force, motion, and energy.	Melon drop Guest speakers from Fortune 100 company discuss engineering design process and collaboration Bouncy ball lab Exit ticket about helmets
2	Students will calculate force and distance based on given quantities. Students will explain Newton's laws of motion.	Coin drop activity Introduction to Newton's laws of motion Google Jamboard™ vocabulary activity – students define force and motion terms in everyday language Station rotations: PhET simulation; force and distance calculations; reading about helmets in the NFL Written summary of effective helmets using force and motion vocabulary
3	Students will investigate and describe applications of Newton's laws of motion.	Article about real-world physics Force drawings in relation to melon drop Introduction to helmet engineering design challenge Small group helmet design brainstorming and sketching Google Jamboard™ gallery walk and peer feedback Helmet design development Exit ticket with speed and force calculations
4	Students will design an effective helmet and justify its design based on their knowledge of	Speed and force calculations Article about how physics informs the design of Olympic athletes' clothing Review of helmet design criteria

	Newton's laws of motion.	Small group helmet design Exit ticket with speed and force calculations
5	Students will design an effective helmet and justify its design based on their knowledge of Newton's laws of motion.	Speed and force calculations Article about the importance of communication skills and active listening Review helmet design and presentation criteria Small group helmet design Preparation for presentation
6	Students will present their helmet designs and the rationale for their designs to a panel of experts.	Final preparation for presentation Small group presentations in Zoom™ breakout rooms (each room with panel of experts) Panelist questions for students Peer evaluation of presentations and participation Google Form™ reflection

Instructional Adaptations

Of the 24 students enrolled in the seventh-grade science class, approximately half consistently attended in person, while the other half attended remotely. Throughout this article, this method of simultaneous, synchronous instruction of in-person and remote students will be referred to as a hybrid approach. In order to ensure access to all of the curriculum materials, individual kits were prepared and delivered to the homes of students participating remotely. In addition, adaptations to the curriculum were required to facilitate participation and communication across students in the classroom and those at their homes. These adaptations will be discussed in more detail in the Technology Integration section below.

Following a classroom COVID-19 exposure, the unit shifted from hybrid to entirely remote starting with Lesson 3. The final lesson was further shifted to entirely asynchronous given a weather-related school closure. Rather than presenting their final designs to the class and a panel of industry engineers in real time, students created recordings of their presentations. They then watched other groups' presentations and provided feedback to one another.

Research Methods and Data Collection

This convergent mixed-methods study included simultaneous collection of quantitative and qualitative data. As part of the broader RPP, we utilized design-based implementation research (DBIR) methodologies, which include collaborative design, testing, and iterative improvement of classroom innovations (Penuel et al., 2011). By making improvements and adaptations to the planned curriculum materials and instructional strategies, this DBIR approach helped ensure that the integrated STEM unit could meet the unique needs of the classroom context (Cobb et al., 2003).

Prior to the start of the unit, the university partners completed a series of training sessions using the Reformed Teaching Observation Protocol (RTOP; Piburn & Sawada, 2000) to ensure inter-rater reliability. The RTOP includes 25 items organized into five sub-scales: lesson design and implementation, propositional pedagogical knowledge, procedural pedagogical knowledge, communicative interactions, and student-teacher relationships. Each item is scored from 0 (never occurred) to 4 (very descriptive of the lesson). Each day of hybrid and remote instruction, the university partners observed via Zoom™ and took observation field notes. Following the observation, they debriefed the observation and discussed each item of the RTOP until they reached consensus on the score, continuing to iteratively refine the RTOP scoring guide to provide clear criteria and examples.

In addition to the RTOP data and observation field notes for both the comparison unit and the STEM unit, data collection for the STEM unit included recordings of planning conversations that took place with the teacher prior to each lesson and ranged from ten minutes to one hour and forty minutes. These conversations focused on reviewing the lesson plans, finalizing any remaining details, and anticipating potential challenges associated with the instructional modality. Following each STEM lesson observation, the four partners met again for a debrief conversation in which they reflected on the day's activities, identified additional needs or adjustments to the upcoming plans, and continued to consider the teaching context. These conversations ranged from 13-23 minutes in length. The university partners utilized the protocol shown in Table 3 to guide the debrief conversations, progressing from general reflection to questions specific to the day's lesson implementation, and closing with identifying steps to ensure success moving forward. Finally, a teacher interview of 37 minutes at the conclusion of the unit focused on the teacher's overall experience and reflections.

Table 3
Debrief Conversation Reflection Protocol

General Reflection	Questions Specific to Lesson Implementation	Looking Ahead
• How did you feel about today's lesson? • What did you think went well today? Why? • What would you do differently if you taught this lesson again? Why would you make those changes? • Where did your students struggle? What support do you think they needed?	• I noticed… [observer describes observation without judgment]. What did you think about that? What prompted you to make that decision? • What do you think would have happened if you… [observer makes suggestion]?	• What would you like to do to prepare for the next lesson? • What can we do to help you prepare for the next lesson?

Data Analysis

Quantitative RTOP data were analyzed using RStudio by running a repeated-measures ANOVA using the anova_test function in the rstatix package (Kassambara, 2021). Qualitative data, including the transcribed planning and debrief discussions and observation field notes, were analyzed using inductive coding methods (Saldaña, 2016). Through iterative codebook development and multiple rounds of coding, the partner assets, challenges, and successes that are described in the following sections were identified. Qualitative and quantitative analyses were compared to conclude whether the results were similar or dissimilar (Creswell & Guetterman, 2018).

Findings

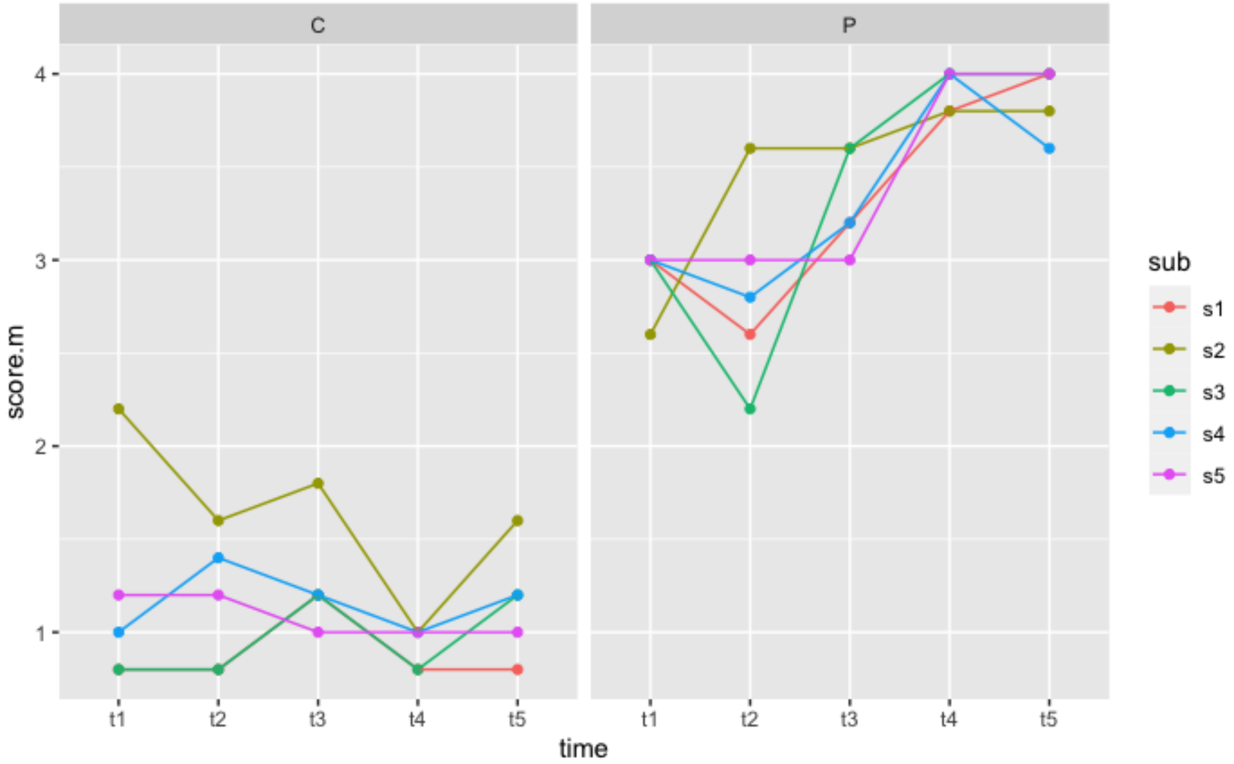
In this section, we share the key findings related to the three research questions. First, we share the results of our quantitative analysis to capture the shift in teaching practices evident based on RTOP data. Second, we share the unique assets of each partner that became central in partner conversations. Finally, we highlight three challenges and successes the teacher encountered throughout the project. For each challenge or success, we include a sub-section that includes a discussion of the relevant research literature as well as recommendations that extend beyond the context of this study.

Shifts in Teaching Practices

Using a repeated-measures ANOVA, the difference in RTOP scores between the comparison unit and the STEM unit was statistically significant [$F(1, 20) = 727.486$, $p<.05$], with a large effect size of 0.822 (Fox & Weisberg, 2019). In addition to the statistically significant difference on the overall RTOP scores, the teacher showed higher RTOP scores on all five sub-scales of the instrument (see Figure 1) as well as every individual RTOP item. Thus, the teacher demonstrated greater use of student-centered, reform-based instructional practices during the STEM unit versus the comparison unit. These instructional practices included small group collaboration, hands-on exploration, and student voice in the activities.

Figure 1

Average RTOP Scores for Comparison Unit (C) and STEM Pilot Unit (P)



Note. The time axis indicates the lesson number (t1 = Lesson 1, t2 = Lesson 2, etc.). The score.m axis is the mean RTOP score for each sub-scale. The sub-scales are grouped items within the RTOP (s1 = lesson design and implementation; s2 = content: propositional knowledge; s3 = content: procedural knowledge; s4 = classroom culture: communicative interactions; s5 = classroom culture: student/teacher relationships).

Partner Assets

Each of the four individuals brought unique assets to the partnership. The recurring planning and debrief meetings provided many opportunities to draw upon these assets to improve the quality of the curriculum materials and instructional practices. Nick had established strong relationships with his students, developing a knowledge of their interests and lived experiences. He had recently completed his undergraduate degree in biology, with minors in chemistry and science, technology, and society. This educational background contributed to Nick's deep science content knowledge, and with medical school remaining a possibility in his future, he was also passionate about science. As a first-year teacher, these assets allowed him to connect with students and excite them about science.

The three university partners, who are the authors of this article, also had distinct assets. The first author was an assistant professor at the university and had been involved in the STEM School project for several years. Her leadership and collaboration within the broader RPP led to a deep understanding of stakeholder needs, constraints, and desired outcomes. She also had expertise in integrated STEM curriculum development and instructional practices, as well as instructional coaching. As a former elementary STEM teacher, she possessed pedagogical content knowledge (PCK), considering the best instructional approach for each STEM topic (Shulman, 1986). The second author was a Ph.D. student at the university and had extensive experience with technology integration. With this experience, he was able to suggest specific technological tools that would support teaching and learning within ERT contexts. As a former agricultural science teacher, he also brought PCK to the partnership, co-leading the design of the instructional materials and pedagogical supports. The third author was also a Ph.D. student at the university and had taught middle school science in the same state as Nick. With her extensive knowledge of state science standards, policies, assessments, and accountability systems, she connected deeply with Nick's context. She also had extensive PCK and co-led the curriculum development.

Challenges, Successes, and Implications

Throughout the integrated STEM unit implementation period, a variety of challenges and successes emerged. In this section, we will discuss the challenges and successes related to technology integration, student discourse, and curriculum development. We will frame the findings from this partnership in relation to what has been learned in other teaching contexts and highlight the implications for teachers in Discussion and Implications sub-sections for each of the three key challenges and successes.

Technology Integration

As the integrated STEM unit was taught in ERT hybrid and fully remote modalities, technology played a central role. With at least some students requiring remote instruction each day, Nick conducted all classes via Zoom™ and made use of his Google Classroom™ to manage assignments. There were challenges with student attendance and Zoom™ participation throughout the unit, and despite the technology affordances, Nick generally saw higher levels of engagement among the students who attended class in person. He also selected technology tools to allow for greater efficiency, to promote collaboration among students, to support students in deepening their understanding of the science content, and to engage students in engineering design activities.

Nick relied heavily on Pear Deck™ to share informational slides and key links with students. This was an efficient means of distributing information, but Nick maintained a high level of control over the activities. He included opportunities for students to respond to prompts within Pear Deck™, enabling in-the-moment formative assessment, but there were few opportunities for students to interact with one another.

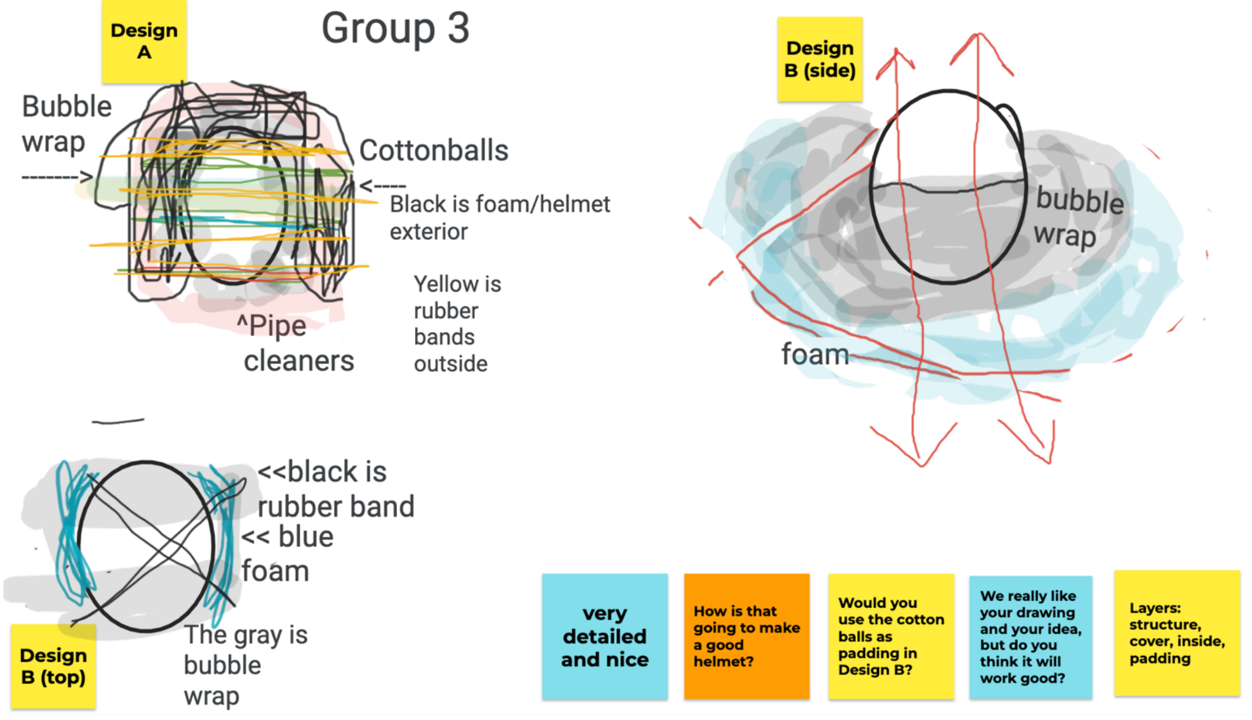
Classkick™ was a new technology that Nick had not used prior to the integrated STEM unit, but he found it beneficial for student collaboration. For example, students completed a bouncy ball lab and were able to work on individual devices but also see and provide feedback on each other's work. With social distancing guidelines in place even for in-person students, this allowed for more meaningful small group interactions. Like Pear Deck™, Classkick™ allowed Nick to simultaneously monitor each student's progress and responses.

Nick was hesitant to use technology tools that released control to the students because he was concerned about how students would use this freedom. Indeed, there were some challenges that arose. For example, the first time that students used Google Jamboard™, they did not use the tool effectively. The Jamboard™ activity was intended to activate prior knowledge and have students begin co-constructing definitions of key vocabulary terms. Each Jamboard™ had a different term (e.g., force, speed, acceleration), and students added words, images, or drawings to reflect what the term meant to them or made them think. Students independently added to the shared workspace with no opportunities for conversation with each other. Few students contributed, and one student added an inappropriate comment, resulting in Nick's early termination of the activity.

However, despite some stress and anxiety following the initial experience with Google Jamboard™, Nick recognized its potential value and persisted in using it. The subsequent instances in which Google Jamboard™ was used were more productive, and students were able to use the platform for effective collaboration among both in-person and remote students. For example, small groups used Google Jamboard™ as a shared space for brainstorming and planning their helmet designs. Groups brainstormed for 10 minutes, simultaneously adding ideas to the Jamboard™ despite not being in the same physical space. They then provided feedback on other groups' designs and revisited their own to address the questions and suggestions they had received. In Figure 2, one group developed two design ideas (Design A and Design B), labeling which materials they intended to use for each. They drew one of their ideas from multiple angles to show how the pieces would be positioned. Comments from other groups are shown in the colored boxes on the lower right; for example, one of the comments focused on their use of cotton balls in one design but not the other, asking whether they would use them for padding. This approach allowed for a collaborative space and a virtual gallery walk in which students saw other groups' ideas and offered feedback to strengthen their designs or help them consider other possibilities.

Figure 2

Google Jamboard™ Small Group Brainstorming and Feedback



very detailed and nice

How is that going to make a good helmet?

Would you use the cotton balls as padding in Design B?

We really like your drawing and your idea, but do you think it will work good?

Layers: structure, cover, inside, padding

Discussion and Implications for Technology Integration. The integrated STEM unit prompted Nick to use new technology tools to meet the need for student collaboration. While the tools were valuable, the process would have been smoother if the students were already familiar with the tools, their capabilities, and expectations related to their use prior to the integrated STEM unit. Rather than using the tools for the first time in a complex activity, we recommend introducing new technology tools in a low-stakes environment. For example, teachers could introduce Google Jamboard™ through a simple polling activity, allowing students to respond to a poll question and cast their "vote" by adding their name to the relevant section of the board. A See-Think-Wonder activity could allow students to use additional Jamboard™ tools, like drawing or adding images, scaffolding their development of Jamboard™ skills before they use them in more complex activities.

For Nick, different technology tools were useful for distinct purposes. Pear Deck™ provided an efficient means for distributing information, whereas Classkick™ and Google Jamboard™ allowed for greater collaboration among students. Both Pear Deck™ and Classkick™ allowed Nick to monitor students' individual contributions very carefully, whereas Google Jamboard™ did not produce a lasting record of which student contributed each element. While each tool is useful, we recommend carefully considering the instructional goals, level of collaboration that is needed, and extent to which individual students will be assessed before selecting a specific tool for a given activity.

When Google Jamboard™ was used without a collaborative element, Nick found it to be less effective. Students often experience decreases in science confidence, or self-efficacy, as they move through the middle school grades (Lofgran et al., 2015), so perhaps they were hesitant to display their individual ideas to the whole class before receiving some level of peer affirmation. As Nick saw when students used Jamboard™ for small group design activities, the open-ended, collaborative use of the technology promoted deeper discussion and engagement. We therefore recommend utilizing Google Jamboard™ when there are multiple "correct" answers or solution pathways. Further, allowing for small group collaboration and shared contributions to Jamboard™ can support deeper student engagement with the content and each other.

Nick identified as a digital native and was familiar and comfortable with technology; however, after teaching for approximately five months, he had selected a few key technologies for use in his classroom and did not consider adding new technologies to his instructional repertoire until prompted to do so by the university partners. Teachers adopt (or do not adopt) technologies for a range of reasons, including the technology's ease of use, its perceived usefulness, its cost, and teacher attitudes toward technology (Aldunate & Nussbaum, 2013; Granić & Marangunić, 2019; Hu et al., 2003). Through the partnership, Nick learned about and utilized new technologies (e.g., Google Jamboard™, Classkick™) that he found to meet unique needs in his classroom, and he planned to continue using them beyond the integrated STEM unit. We recommend creating an intentional space for teachers to share their use of various technology tools with one another, including discussions of the tools' affordances and limitations. For example, schools could have dedicated professional learning time during which teachers discuss shared problems of practice (including technology-related), plan inquiries into possible solutions, and then share the results of their inquiries, both positive and negative. Discussion of implementation strategies, challenges, and successes can help teachers feel more comfortable experimenting with new technology tools and persisting in their use despite setbacks. With ongoing sharing and exposure to new technologies, teachers can more carefully consider their instructional needs and select technologies accordingly rather than defaulting to what is already familiar to them.

Student Discourse

Throughout the year of implementing ERT in both fully remote and hybrid modalities, Nick struggled to incorporate opportunities for students to engage in meaningful student-teacher and student-student discourse. Because he relied heavily on teacher-centered, lecture-based instruction as an efficient and manageable approach to ERT, most opportunities for student discourse were in the form of responding to teacher questions, which often had a single correct answer. These questions often resulted in a typical classroom pattern of initiate-respond-evaluate (IRE), maintaining Nick's central position in receiving and legitimizing student responses. While Nick desired deeper forms of student discourse, the challenges with teaching both remote and in-person students simultaneously and low participation rates among students were significant barriers.

When implementing the integrated STEM unit, Nick was pushed beyond his comfort zone in facilitating student discourse when a single correct answer was not expected. Because the unit included an open-ended design challenge with multiple possible solutions, students shared a variety of ideas in both small group and whole class settings. The path of classroom discussions was therefore less predictable to Nick, requiring more immediate decisions about whether and how to pursue student ideas versus when to redirect the conversation. Although this was challenging, he also recognized that new student voices were being heard in the classroom and that students were developing skills in having productive conversations among themselves.

These opportunities for student discourse required advance planning of discussion prompts that would evoke meaningful conversation. They also required advance attention to logistics, such as how in-person and remote students would connect with each other. The importance of this clear planning became evident when Nick made in-the-moment modifications to the lesson plans. These spontaneous adjustments often resulted in him defaulting to direct instruction, resulting in IRE discourse patterns. For example, during the melon drop activity, Nick became uncertain about whether students understood the forces acting upon the melon. He shifted from a discourse pattern in which students were co-constructing understanding of the phenomenon together, to a lecture about forces with few opportunities for student input.

Discussion and Implications for Student Discourse. Student discourse in science has long been accepted as central to learning (e.g., Lemke, 1990), but research indicates that opportunities for scientific discourse are often limited, particularly in school settings with a high proportion of students from racial and ethnic minorities (e.g., Bae, DeBusk-Lane, et al., 2021; Manz, 2015). Serving predominantly Latinx and Black students, Nick's tendency toward direct instruction of groups historically underrepresented in science was observed in the present context as well.

Facilitating productive science discussions includes moving beyond a basic elicitation of student ideas to uncover students' science ideas (both accurate and inaccurate), build on these ideas, challenge students to provide evidence and reasoning, and move the group toward a deeper understanding of the subject matter (Carpenter et al., 2020; Roth et al., 2017). With an increasing focus on the use of science and engineering practices within K-12 classrooms (NGSS Lead States, 2013; NRC, 2012), the range of instructional goals for student discourse is broad. Within the integrated STEM unit, students engaged in a number of science and engineering practices, including defining the engineering problem, carrying out investigations, analyzing data, designing solutions, constructing arguments based on evidence, and communicating information. The discourse demands of these tasks were high, particularly given the shift from largely lecture-based instruction prior to the integrated STEM unit.

It is therefore important to consider how to scaffold student discourse. Previous studies related to supporting student science discourse have found that a range of scaffolds, including templates, diagrams, and discussion prompts, promote deeper discourse and learning (Bae, Mills, et al., 2021; McFadden & Roehrig, 2019; Lombardi et al., 2018). The integrated STEM unit included multiple scaffolds for student discourse. For example, after students developed design ideas within their small groups, a virtual gallery walk and peer feedback process was used to encourage students to provide constructive feedback to other groups. To support the provision of specific and useful feedback, sentence stems were provided: "We really like…," "What if you…," and "How are you going to…?" Additional templates for products could have further scaffolded student work. For example, a Google Jamboard™ template with designated areas for drawing a design, explaining it in words, connecting to science ideas, and thinking about potential problems or challenges with the design could have promoted deeper thinking about the design process.

In addition, providing general scaffolds may not be enough to ensure equitable participation, particularly within small group settings. Open-ended STEM activities present unique challenges to students within small groups, resulting in an inequitable distribution of power and responsibility, often differing based on gender and race/ethnicity (Wieselmann et al., 2020; Wieselmann, Dare, et al., 2021; Wieselmann, Keratithamkul, et al., 2021). Additional scaffolds should therefore be included with the goal of supporting equitable participation in small group activities. For example, discussion protocols in which each group member has a designated amount of time to share their ideas can help ensure that conversations are not dominated by certain individuals.

While student discourse is central to effective integrated STEM teaching, it does require careful consideration. Discussion prompts, scaffolds, and procedures to support equitable participation in discourse activities must be thoughtfully planned. In addition, teachers should consider their role in discourse and identify a clear approach for disrupting patterns of inequity they observe.

Curriculum Development and Professional Learning

In this partnership, the integrated STEM curriculum unit served as both a culminating product and as a pedagogical tool to support effective teaching practices. Within the partnership, the curriculum materials were iteratively developed over time, with each day's planning and debrief meetings shaping the lessons. Each partner leveraged their own assets to strengthen the unit. For example, Nick was well equipped to bring student interests and lived experiences into the lessons, so in areas where the original examples were deemed irrelevant (e.g., a skiing example when few students had ever been skiing), Nick improved the lesson with more personally meaningful connections. He also recognized an opportunity to connect helmet design to a previous unit on animal adaptations, considering how woodpecker and ram adaptations help prevent the animals from head injuries. When the third author recognized opportunities to reinforce concepts and vocabulary that were often heavily weighted in district and state assessments, the lessons were adjusted accordingly. Further, her experience teaching English Learners revealed the importance of clearly distinguishing between speed and velocity, given the term "velocidad" means speed in the Spanish language. In this way, the partners worked together to develop a final curriculum product that was appropriate for the local context and population of students.

While these lesson modifications were a valuable aspect of the partnership, the curriculum also served as a tool for promoting Nick's use of student-centered instructional strategies. Nick was free to modify lesson activities in the planning phase or in the moment during instruction, but the rationale provided for the activities within the curriculum pushed him to move beyond his comfort zone and utilize new approaches. The curriculum detailed specific approaches to engaging students in student-centered learning; for example, it called for collaborative lab activities, open-ended design, and communication among students, positioning Nick as the facilitator and reflecting a shift from his typical lecture-based instruction. The expertise and firsthand teaching experience of the authors supported Nick in making these shifts, anticipating challenges and ways to overcome them. Nick found collaborative planning and debrief discussions to be incredibly valuable. Given the many demands on teachers' time, he did not typically experience this type of co-planning activity. By discussing the lessons both before and after teaching them, he felt he was able to refine his teaching strategies and recognize additional areas for growth as a teacher.

Discussion and Implications for Curriculum Development and Professional Learning. The focus on real-world problems within the integrated STEM unit offered a number of opportunities to support student learning and to promote Nick's growth as a teacher. Davis and Krajcik (2005) emphasized that curriculum materials can be used to support both teacher and student learning. They highlight several curriculum aspects that can promote teacher learning, including helping teachers anticipate what students will think and do in relation to the lesson activities, drawing connections across instructional units, justifying pedagogical decisions, and promoting the teacher's own ability to develop and adapt curriculum materials (Davis & Krajcik, 2005). Each of these elements played out in the present context; however, the curriculum materials worked in concert with the corresponding planning and debrief conversations for educative purposes. The opportunity for Nick to contribute ideas, ask questions, and troubleshoot potential challenges with the university partners supported deeper growth than may have been prompted by static curriculum materials alone. When Nick made connections between helmet design and animal adaptations, the first author recognized an opportunity to connect to the broader crosscutting concept of structure and function (NGSS Lead States, 2013; NRC, 2012). Both Nick and the university-based partners brought unique knowledge to the partnership, and it was the rich discussions of lesson activities that allowed for deep connections across units to be made. Collaborative curriculum development and co-planning opportunities grounded in school-university partnerships can lead to more effective, context-appropriate curriculum materials.

In addition to allowing for connections across units, the daily planning and debrief discussions served to deprivatize teaching, both for Nick and for the university-based partners. Nick's instructional practices were on display throughout each day of lesson implementation, providing a shared understanding of the classroom context and his instructional decisions. In planning for and reflecting upon instruction, these concrete examples allowed for deeper discussion. In addition, throughout the planning and debrief sessions, all of the university-based partners also described their own teaching practices, including things that worked well and those that did not. In this way, Nick was able to learn from the "mistakes" the others had made, avoiding some potential pitfalls in the process. This was particularly significant given the drastic shift from teacher-centered to student-centered instruction and the many logistical challenges associated both with hybrid instruction and with integrated STEM instruction in general. While classroom observations are part of many districts' formal teacher evaluation and accountability plans, the extended nature of the classroom observations, as well as their non-evaluative nature, allowed for ongoing and thoughtful reflection on teaching practices. University partners may be able to support these efforts to inquire into teaching practices by observing classroom instruction, modeling classroom instruction, supporting lesson study or instructional rounds, or facilitating video-based lesson analysis. Teachers have few opportunities to observe others, and these additional opportunities to discuss, view, and reflect upon different approaches to teaching can be rich learning experiences for both school-based and university-based partners.

Discussion

Implementing an integrated STEM unit in ERT circumstances presented a number of challenges for the school and university partners. Planning and carrying out the unit required additional planning time and ongoing flexibility as the COVID-19 context shifted. Despite these challenges, the opportunity for collaboration was viewed positively by both Nick and the university partners. Nick reflected on his instructional practices and recognized that he grew in his technology integration and his ability to engage students in authentic learning. He saw increased student discourse and higher levels of engagement among students, and in describing the experience, Nick remarked, "This is the most fun I've had teaching." Nick was particularly appreciative of the opportunity to discuss teaching with former teachers, unconstrained by typical professional learning community structures. These conversations addressed everything from logistical considerations to pedagogical content knowledge for how best to teach certain topics. Indeed, research has indicated that teachers learn while working alongside other teachers in collaborative efforts that make instructional practices public, and this learning can support teacher leadership as well (Lieberman & Friedrich, 2010).

While the school-university collaboration was positive for all of the partners, two key tensions became apparent. First, Nick was conflicted about how much control to release to his students throughout the unit. He struggled to balance student agency and teacher control of the learning environment, particularly because he was accustomed to maintaining a highly controlled classroom. The integrated STEM unit prompted him to utilize new technologies for collaboration among students, promote student discourse, make connections to student lives and experiences, and provide design activities with multiple solutions and multiple solution pathways. All of these elements shifted power from Nick to the students and created a more complex learning environment in which different groups of students progressed at different paces. Although there were some challenges around setting expectations for how students would make use of this agency, both Nick and his students ultimately embraced the opportunities. This tension between student agency and teacher authority during inquiry-based instruction has been well-established in the research literature (e.g., Buzzelli & Johnston, 2001; García-Moya et al., 2019; Tan & Wong, 2012). However, there is a growing recognition that classroom authority can be shared among the teacher and students (Brubaker, 2012; Kim, 2021; Oyler, 1996). Future work should include intentional efforts to support teachers in developing a shared classroom authority.

Second, tension between authentic learning opportunities and accountability testing was apparent throughout the partnership. Previous studies have demonstrated that teachers perceive the integration of engineering within science instruction as conflicting with mandated tests (Hutner et al., 2022). While integrated STEM units often focus on conceptual development and the co-construction of knowledge, this can be at odds with student accountability and preparation for vocabulary-heavy standardized tests (Marshall et al., 2021). Nick repeatedly expressed feeling this tension between engaging his students in integrated STEM activities and preparing them for standardized testing. Because this was Nick's reality, the university-based partners sought to identify strategic opportunities to incorporate test preparation activities. For example, rather than dedicating an entire lesson to lecture and practice test questions, select questions were used as "bell-ringer" or exit ticket activities at the start and end of the lessons to demonstrate what had been learned without compromising the key lesson activities. The university partners emphasized using these practice questions as a means of formatively assessing student learning. The third author's deep understanding of the state assessment also allowed for the recognition of key opportunities to reinforce vocabulary and concepts within the integrated STEM activities.

Limitations

While this study provides helpful information about the challenges and successes an early-career teacher faced while implementing integrated STEM instruction for the first time, two key limitations must be considered. First, the teacher utilized ERT to implement the integrated STEM unit during the COVID-19 pandemic. While this contextual factor was a central element of the project and motivation for the study, it is likely that different challenges and successes would emerge with either fully in-person or established online/distance learning instructional models. Second, the findings represent the experiences of one teacher. Although some of the lessons learned likely transfer to other teachers, caution must be taken in generalizing specific findings to the broader population of early-career teachers.

Conclusion

The school-university partnership described in this article was unique in many ways. The broader partnership between a mid-sized private university, a large urban school district, a Fortune 100 company, and local community partners seeks to develop an innovative and collaborative approach to education. Aiming to bridge K-12 education and the university setting, the partner roles spanned boundaries between these two distinct entities. Both the school and university partners took up roles that are not typical in their positions, creating a third space to link the settings (Zeichner, 2010). Further, the COVID-19 pandemic, ERT, and weather-related school closures further underscored the unique aspects of the partnership. Despite these distinctive elements, the learning from this partnership can extend beyond the immediate context.

The integrated STEM unit was implemented within the ERT context and required a significant amount of planning and resources. Notably, the resource structures surpassed the typical scope of the school and university. STEM kits were assembled by the university partners and distributed to the students by Nick. Daily meetings to reflect upon previous lessons (see Table 3) and strategize for upcoming lessons required an investment of time from all partners. These dedicated resources enabled the success of the partnership, and those who desire to develop and sustain partnerships in new contexts should develop a clear shared plan for ensuring access to needed resources and structures, such as discussion protocols, for using time effectively.

The partnership described in this article was characterized by ongoing commitment to professional learning by all partners. Nick viewed the opportunity to improve his teaching practice as a valuable affordance of the partnership, and the university-based partners saw rich opportunities for learning how to support early-career teachers in implementing integrated STEM instruction in ERT modalities. The individual goals coalesced into a meaningful partnership that was mutually beneficial. When developing partnership plans, it is critical to consider the assets, needs, and constraints of each partner or institution. We recommend having an explicit discussion of these elements early in the planning phase, but it is also necessary to revisit the conversation throughout the partnership. By articulating these expectations up front and recognizing when they shift, partnerships can work toward positive outcomes for all stakeholders.

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