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Engineering 'STEAMs' Up Elementary Education: Impacts of the COVID-19 Pandemic (Fundamental)

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Abstract

The problem is that COVID-19 radically changed teaching and learning at a time when many public school districts were still aligning to their state’s new science, technology and engineering (STE) curriculum frameworks. When the pandemic hit the United States by March 2020, teaching and learning went completely remote for the majority of schools. Teachers abruptly learned new strategies and technologies to facilitate remote teaching while students faced challenges with remote learning, self-directed learning, isolation from friends and teachers, and equitable access to the Internet and computer devices. STEAM Labs and science equipment were inaccessible. With an emphasis on math instruction, ELA instruction and students’ social and emotional learning needs, remote and hybrid teaching and learning involving science and engineering were not a priority for elementary teachers and their district administrators, even as COVID-19 health protocols and restrictions eased into the 2021 – 2022 academic year.

Fullan’s educational change theory was used to investigate the impact of STEAM education in 2 public school districts as they aligned to new state STE curriculum frameworks. A mixed methods, embedded case study approach was used to explore how sixteen (16) elementary teachers and six (6) district leaders implemented revised STE curricula before and during the pandemic. This study investigated the research question “How does the presence of science, engineering and technology curricula and STEAM Labs, and in particular *their absence during COVID-19*, impact elementary education and the implementation of new science, technology and engineering (STE) curriculum frameworks?”. Study participants were invited between December 2021 – February 2022 to complete an online qualitative and quantitative survey which was designed using questions from previously published self-efficacy and teacher experience instruments. Participants were also invited to discuss their experiences during a virtual interview.

Results indicate that COVID-19 continued to disrupt STE teaching and learning through the 2021 – 2022 academic year and that STEAM Labs, collaborative group work, and investigative problem solving skills were *missing* from STE instruction. Findings reveal that there is renewed interest in project-based learning, inquiry-based learning, innovative pedagogy, STEAM Labs and engineering as the “keystone” to STEAM education, especially as COVID-19 health protocols and restrictions subside. To apply the results of this study, researchers and professional development providers should continue to engage teachers in continuous, embedded professional development that focuses on engineering pedagogy, engineering practices and teacher self-efficacy to help integrate STEAM education. Future research should also follow the short-term and long-term integration of engineering into elementary education to study *student* outcomes, especially longitudinally. As much as COVID-19 continued to disrupt STE teaching and learning, it has reminded educators that the need to provide high-quality science, technology, and engineering education is even more urgent.

Introduction

The primary purpose of this study was to investigate the experiences of district administrators and elementary school teachers who develop, design and implement new curricula that align to the 2016 Massachusetts science, technology and engineering (STE) curriculum frameworks [1]. This paper focuses on a specific sub-set of research data collected during the author's doctoral dissertation that have not yet been published.

The acronym STEAM (science, technology, engineering, art and mathematics) has emerged as a more inclusive approach to STEM education because it incorporates the arts [2]. STEAM education includes the study of art, drama, music, media and design, which is increasingly becoming more technical with the development of computer-aided software for musicians, architects, graphic artists and artists using almost any media. In this study, STEAM education was the preferred term and is inclusive of STEM education as well.

Researchers and engineering educators have long been evaluating the effectiveness of engineering education in the K-12 grades, particularly with respect to engineering and engineering's impact on successful STEM integration. The National Academy of Engineering's (NAE) report *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* emphasized that the report committee "is even more interested in seeing engineering education become a catalyst for improved learning in the other STEM subjects" [3]. "There is considerable potential value, related to student motivation and achievement, in increasing the presence of technology and, especially, engineering in STEM education in the United States in ways that address the current lack of integration in STEM teaching and learning" [3].

Historically, STEM education has primarily focused on science and mathematics, with engineering, technology, and art as secondary subjects. Even in modern times in Massachusetts, the first state to incorporate engineering into their K-12 science standards in 2006, the Massachusetts Department of Secondary and Elementary Education only focuses on science and math in their teacher professional development programs: "Science and mathematics content training are the primary focus of STEM's professional development efforts." [1]. Support for integrating STEM education originated decades ago, notably in Rodger Bybee's 2013 book The Case for STEM Education: Challenges and Opportunities [4]. In this publication, Rodger Bybee identified the ambiguity of "STEM" and how STEM "referred to whatever the individual or group was doing." [4] He explained that "Most often, STEM referred to either science or mathematics. Much less often did STEM address technology and engineering." [4]. Bybee went on to outline local, state and federal strategies for developing and reforming STEM education and identified models of what STEM integration could look like with a focus on students achieving higher levels of STEM literacy. He illustrated what STEM education may look like in a school or district as 4 separate disciplines, science, technology, engineering and math, with science and math as the clearly visible "silos" while technology and engineering are the somewhat visible "postholes" in between that may be void of any curricula or instruction, depending on the setting. He emphasized that "Technology is greater than computers and more than a means of teaching." [4] He also wrote that there is a "need to recognize technology and engineering as full members of the STEM quartet of disciplines". [4]

A more recent Consensus Study Report *Building Capacity for Teaching Engineering in K-12 Education* by the National Academies of Sciences, Engineering and Medicine [5] was commissioned to understand current and future needs of engineering-literate K-12 educators in the United States and to suggest actionable steps to better address such needs. This 3-year study, led by a committee of prominent educators, researchers and industry leaders from public, private and non-profit organizations, investigated the preparation of K-12 engineering educators, professional pathways for K-12 engineering educators and the role of higher education in preparing and supporting K-12 engineering educators in mostly formal, not informal, education. They discerned 4 goals of K-12 engineering education, stating that "all teachers of K-12 engineering should be able to teach to the goal of engineering literacy" [5]:

1. develop engineering literacy;
2. improve mathematics and science achievement through the integration of concepts and practices across the STEM fields;
3. improve college and career readiness; and,
4. for a small percentage of students, prepare for matriculation in postsecondary engineering programs.

The second goal points out the role of engineering education as a way to integrate concepts and practices across all STEM fields, a testimony to engineering's importance in STEAM education. Of the many recommendations that the report outlined with actionable steps, the committee's primary achievement was "to alert constituencies with a stake in United States STEM education to the mismatch between the need for engineering-literate K-12 teachers and the education system's lack of capacity to meet this need." [5]. These conclusions point to the bigger problem that integrated STEM/STEAM teaching and learning have not yet been achieved but that a potential solution involves engineering education as an essential spark to that integration.

The COVID-19 pandemic is still impacting elementary education in several ways, especially science, engineering and technology education. When the pandemic hit the United States by March 2020, teaching and learning went completely remote for the majority of schools. Teachers abruptly needed to learn new strategies and technologies to facilitate remote teaching while students faced challenges with remote learning, self-directed learning, isolation from friends and teachers, and equitable access to the Internet and computer devices. STEAM Labs and science equipment were inaccessible, yet some teachers improvised as best they could under the circumstances to design "home" versions of inquiry investigations and science experiments. With an emphasis on math instruction, ELA instruction and students' social and emotional learning needs, remote and hybrid teaching and learning involving science may not have been a priority for elementary teachers from March 2020 to March 2021 (and even as of this writing in 2023), when many elementary schools were still operating in a hybrid (part in-person, part remote) system. In a recent survey cited in a National Academies report *Teaching K-12 Science* *and Engineering during a Crisis*, 88% of teachers indicated that their students were spending less time on science through remote learning than they had in the classroom, and only 38% of teachers reported that students had been engaged in experiments or investigations through remote learning [5]. Educational system recovery measures from the pandemic and subsequent student outcomes are just starting to emerge but early research, as cited above, indicates that the pandemic has undoubtedly impacted students and teachers [6].

New Curriculum Frameworks

In April 2016, the Massachusetts Department of Elementary and Secondary Education adopted a new Science and Technology/Engineering (STE) Curriculum Framework [1]. Since several years would be required for standardized test questions to align to the new science standards, some school districts began planning in 2013 when the new draft standards were published for public review and comments. However, despite some school districts beginning the process early, most did not formally begin planning and implementation until 2016. In Massachusetts, the integrated science / technology / engineering standards are only assessed in a total of three grades (5, 8 & 10) while mathematics is assessed in a total of seven grades (3 – 8 & 10). The fact that mathematics is formally assessed every year between 3rd – 8th grade and once in grades 9 – 12 due to the 2001 Elementary and Secondary Education Act (ESEA) [7], also known as the No Child Left Behind law, and the 2015 Every Student Succeeds Act (ESSA) [8], explains why so much of the school day is dedicated to math education and not to science / technology / engineering education in most public schools. Therefore, although Massachusetts has decided to integrate science, technology and engineering with its new standards, a truly integrated STEAM approach to education which includes mathematics and art may have only been achieved by a few "STEM" or "STEAM" schools.

Research Question

This component of the study investigated the research question: *how* does the presence of science, engineering and technology curricula and STEAM Labs, and in particular *their absence during COVID-19*, *impact* elementary education and the implementation of new science, technology and engineering (STE) curriculum frameworks?

Research Methods

A mixed methods, embedded case study approach [9] was used to explore how elementary teachers and district leaders implemented revised STE curricula before and during the pandemic and how the pandemic impacted their teaching. A mixed methods research approach was chosen because it is rich in multiple sources and converging evidence. Case study, specifically Yin's case study approach, has been used in previous engineering education research. For example, a qualitative research study using Yin's embedded single-case study approach was used to investigate teachers' engineering practices as part of a professional development program (the case) with their engineering lessons as the embedded units of analysis to determine the extent of teachers' engineering integration abilities [10]. Another engineering education study that used a multiple case study design by Yin was a preschool classroom observation study of "engineering habits of mind" [11] that used the Teaching Engineering Self-Efficacy Scale (TESS) instrument [12].

The current study followed typical qualitative and quantitative data collection protocols and protections for online surveys and virtual interviews with adult human subjects as this study did not include minors. Institutional Review Board review #CPS21-09-10 with the author's dissertation advisor at the host institution was approved in Fall 2021 and the study commenced shortly thereafter.

Theoretical Framework

Fullan's educational change theory was used to investigate the impact of STEAM education in 2 public school districts as they aligned to new Massachusetts Science, Technology and Engineering curriculum frameworks between 2016 - 2022. The main tenets or phases of Michael Fullan's educational change theory are initiation, implementation and continuation (or institutionalization) [13]. According to Fullan, there are several reasons why people or organizations initiate change: "personal prestige, bureaucratic self-interest, political responsiveness, and/or commitment to solving an unmet need" [14]. Within the context of this research study, STEAM professional development is one solution toward solving an unmet need in which teachers may lack sufficient knowledge of 21st century science and engineering content and pedagogies. In the implementation phase, "how change is put into practice determines to a large extent how well it fares" [13]. According to Fullan, implementation refers to what actually happens in practice, as opposed to what was supposed to happen. In other words, "planned change attempts rarely succeed as intended" [13]. Continuation refers to whether the change is incorporated into the system or disappears through attrition. Continuation depends on various factors such as leadership, continuous professional development, communication and commitment among all the stakeholders (teachers, administrators, students, parents and the community). Measurable outcomes such as improved student learning and attitudes, new skills, satisfaction on the part of teachers and administrators or the improved problem-solving capacity of the school as an organization are usually the desired results of educational change reform [13]. The single most important idea about educational change is that "change is a process, not an event" [13].

This statement that change is a process, not just for the organization but for *every* teacher, student, staff member, administrator, parent and community member, has authentic constructivist origins. According to Fullan, "any significant innovation, if it is to result in change, requires individual implementers to work out their own meaning" [13]. In other words, effective implementation of change is not what one person or group envisions as success but is a "process of clarification" for each stakeholder, just like constructivist approaches used to generate experiential knowledge such as project-based, problem-based and inquiry-based learning. Similarly, since case studies are constructivist in that the experiences of the participants shape how the participants themselves make meaning of their own truth and knowledge, educational change theory lends its perspective to complement case study research methods.

For context, Fullan's educational change theory has been used to study change in engineering education at the university level [15]. In their paper, Kolmos et al. applied Fullan's framework to stakeholder values and culture to re-build undergraduate engineering curriculum using initiation, continuation and implementation. Therefore, since the effectiveness of engineering education as a catalyst to implement STEM/STEAM integrated teaching and learning in preK – 12 classrooms was of primary interest in this research study, educational change theory could reconcile such unknown questions about engineering education's impact on STEAM education. And since educational change theory allows participants to make meaning of their own experiences, a constructivist case study was justified.

Participants

Sixteen (16) self-contained classroom teachers and six (6) administrators were recruited from a potential pool of 130 preK-5 full-time equivalent teachers and 16 administrators in two (2) Massachusetts public school districts. Potential participants were identified through the public website directories of each district by school and grade and confirmed by each assistant superintendent. These 2 public school districts were chosen because the author had previously delivered continuous, embedded professional development over several years to help teachers unpack their new STE standards and to revise their curricula, especially in engineering topic areas. Self-contained was defined as a teacher who teaches multiple subjects to a single class of students.

All potential participants were invited to participate in the research study between December 2021 – February 2022 by completing an online survey about their teaching experiences before, during and "after" the COVID-19 pandemic. Seven of the teacher participants also agreed to a follow up virtual personal interview. All six of the administrators agreed to a follow up virtual personal interview. All the teacher participants in this study were white, non-Hispanic/Latinx women, average age 52 years old, range 27 – 62 years old. The average number of years teaching science for all teachers was 16 years, range 1 – 31 years. All district administrators reported that they were white, non-Hispanic/Latinx, average age 51 years old, range 38 – 63 years old. All district administrators were women except for 1 man. The average number of years teaching science for all administrators was 12 years, range 6-18 years.

Substitute teachers that served in short-term roles of less than one year were excluded from the study as their circumstances may not represent a typical career teacher in that school and/or grade level. District administrators who were not involved in the process of aligning their current school to the new Massachusetts science, technology & engineering curriculum frameworks anytime between 2016 – 2021 were excluded from this study. Instructional technologists were excluded from this study because they are not primarily responsible for teaching the new science, technology, and engineering curricula compared to classroom teachers who are responsible in these districts. There were no science specialists in these districts.

Instruments

Survey data was first collected using confidential Google Forms (one survey for the teachers, another survey for district leadership personnel) administered electronically by the researcher using a secure institution-sponsored computer account. Each survey was available for 8 weeks with targeted email reminders to teachers and administrators who had not responded to the invitation to complete the survey at the end of weeks 2 and 4, with 5 days left in the data collection period, and finally on the last day of data collection. A survey completion rate of 50% or more was the target, to achieve a sample of at least 65 teachers and at least 8 district administrators. The actual survey completion rate for teachers was 12% and for administrators 37.5%. Personal interviews were conducted after participants completed their Google survey.

Survey questions and interview questions were designed to engage participants in their own experiences, allowing open-ended responses when appropriate that were coded and analyzed qualitatively. Survey data were collected as agree/disagree Likert-scaled questions, open-response questions, multiple choice questions, and demographic questions. Some survey questions were modeled after the Report of the 2018 National Survey of Science and Mathematics Education (NSSME+) [16] to capture teacher demographics, educational background, and professional development experiences. Some survey questions focused on teaching experiences and questions about science/engineering instruction before, during and after COVID-19 using the *Teacher Efficacy and Beliefs toward STEM Survey* (T-STEM) [17].

Data Analysis

Personal identification information such as names and email addresses were removed from the working set of data to "blind" the researcher during data analysis, especially in the quantitative survey results. A unique personal identification number was used to connect data across surveys and personal interviews, for the purpose of unbiased data analysis. This strategy is considered standard research practice and is designed to remove bias. It was this researcher's responsibility to maintain confidentiality on behalf of the study's participants and stakeholders by using pseudonyms in place of actual names.

Qualitative data analysis included creating transcription documents of each virtual interview using Zoom software. A running "codebook" was maintained to aid in the first cycle and second cycle coding process. Coding was done both manually in Microsoft Word with comment boxes to engage the researcher fully into the data and then repeated and stored electronically using NVivo 12 Pro. For the first cycle of coding, descriptive coding, attribute coding, process coding and in-vivo coding [18] were used and documented using NVivo 12 Pro.

Quantitative data analysis of relevant survey questions, especially including demographic and background education data, included descriptive statistics, where appropriate. Likert scale data (*strongly agree* to *strongly disagree*) that use a quasi-interval (ordinal & interval) scale were collected with the intent to use parametric tests but only if the data is considered normally distributed and the distance between each scale value is equal. Other scales (*highly important* to *of no importance*) were considered ordinal (ranking scale, for example) because the intervals between responses may not be equal and will, therefore, require nonparametric tests. Likert interval scales were numerically scored 1 – 5 with *strongly disagree (1), disagree (2), neither agree/nor disagree (3), agree (4)* and *strongly agree (5)* and considered normally distributed and with equal interval delineations.

Quantitative Results

Quantitative evidence for how COVID-19 disrupted STE teaching and learning were collected through teacher surveys that were administered between December 2021 – February 2022. These five questions were directed at 2 different time periods (prior to COVID-19 and during COVID-19 of the 2020 – 2021 academic year):

1) *Which BEST described your science teaching? (*with a frequency response of when science was taught)
2) *How often did your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?*
3) *How often did your students work in small groups during STEM instructional activities?*
4) *How often did your students complete STEM instructional activities with a real-world context?*
5) *How often did your students engage in STE lessons in a STEAM Lab or makerspace?*

Question 1) Which BEST described your science teaching?

Before COVID-19, the majority of teachers (10 out of 16) reported that they taught science "all or most days, every week of the year" (n = 2 blue bar, left graph) and "every week, but typically not every day of the week" (n = 8, green dotted bar, left graph) (Figure 1). During the 2020 – 2021 academic year, the majority of teachers (10 out of 16) reported that they were only teaching science "some weeks, but typically not every week" (n = 10, orange mesh bar, right graph) (Figure 1). This shift to less frequent science teaching overall can be directly attributed to the responses of six teachers while 8 of 16 teachers did not change frequency and two different teachers did not teach science (one before COVID and the other during COVID). Therefore, the main takeaway from this data is that the second most frequent science instruction ("every week but not every day", green dotted bars in Figure 1) dropped to a less frequent occurrence ("some weeks but not every week", orange mesh bars in Figure 1), evidence that COVID-19 disrupted the frequency of science instruction.

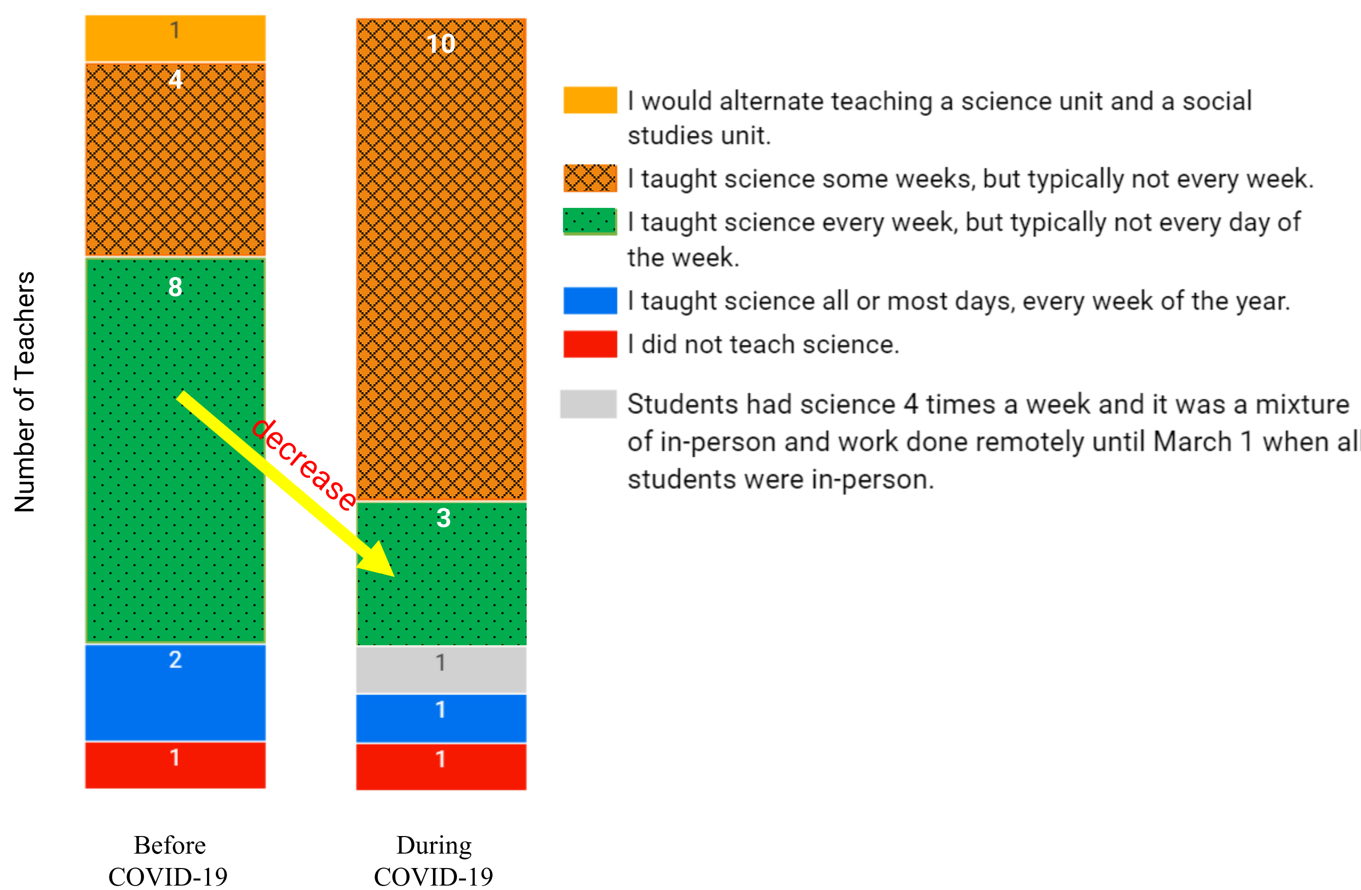

Figure 1. Frequency of Science Teaching Before and During COVID-19, as Reported by Teachers (n=16).

In fact, one 1st grade teacher confirmed: "*Due to the impact of COVID-19 and the need for teachers to deliver a set amount of literacy and math instruction during the day, students are often not exposed to science topics as frequently or with much less explicit instruction.*"

Question 2) How often did your students develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations)?

Before COVID-19, the majority of teachers (11 out of 16) reported that their students developed problem-solving skills through investigations at least "usually" or "every time" (Figure 2). During COVID-19, this frequency dropped with only 6 out of 16 teachers reported "usually" and none reporting "every time". This question was selected because problem solving through scientific or design investigations is an important engineering skill.

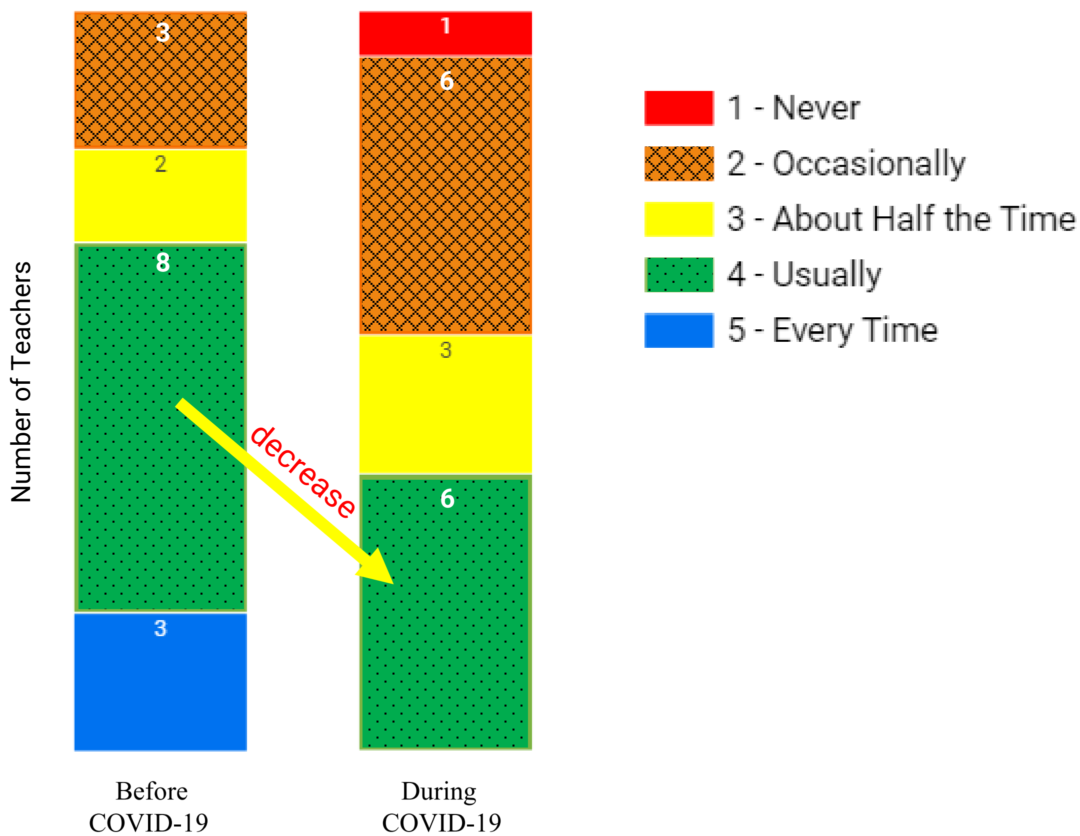

Figure 2. Frequency of Students Developing Problem-Solving Skills Before and During COVID-19, as Reported by Teachers (n=16).

Question 3) How often did your students work in small groups during STEM instructional activities?

Before COVID-19, an overwhelming majority of teachers (15 out of 16) reported that their students worked in small groups "usually" and "every time" (Figure 3). During COVID-19, this frequency dropped to only 3 out of 16. During COVID-19, the majority of teachers (12 out of 16) reported that their students "never" or "occasionally" worked in small groups. As expected, COVID-19 health protocols impacted teachers' instructional activities.

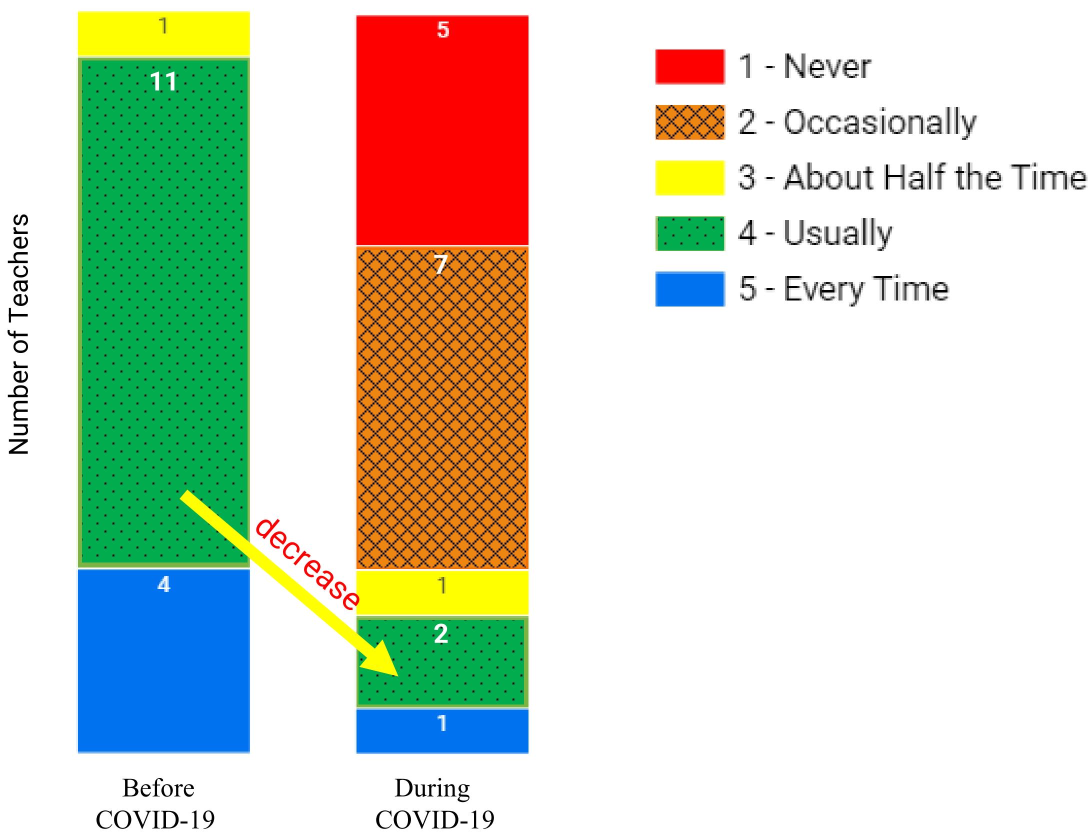

Figure 3. Frequency of Students Working in Small Groups Before and During COVID-19, as Reported by Teachers (n=16).

Question 4) How often did your students complete STEM instructional activities with a real-world context?

Before COVID-19, a majority of teachers (11 out of 16) reported that their students completed STEM instructional activities with a real-world context "usually" and "every time" (Figure 4). During COVID-19, this frequency dropped to only 6 out of 16 teachers reporting these frequencies. During COVID-19, the majority of teachers (10 out of 16) reported that their students "never", "occasionally" or "about half the time" completed STEM instructional activities with a real-world context. This question refers to the importance of authentic STEM teaching and learning.

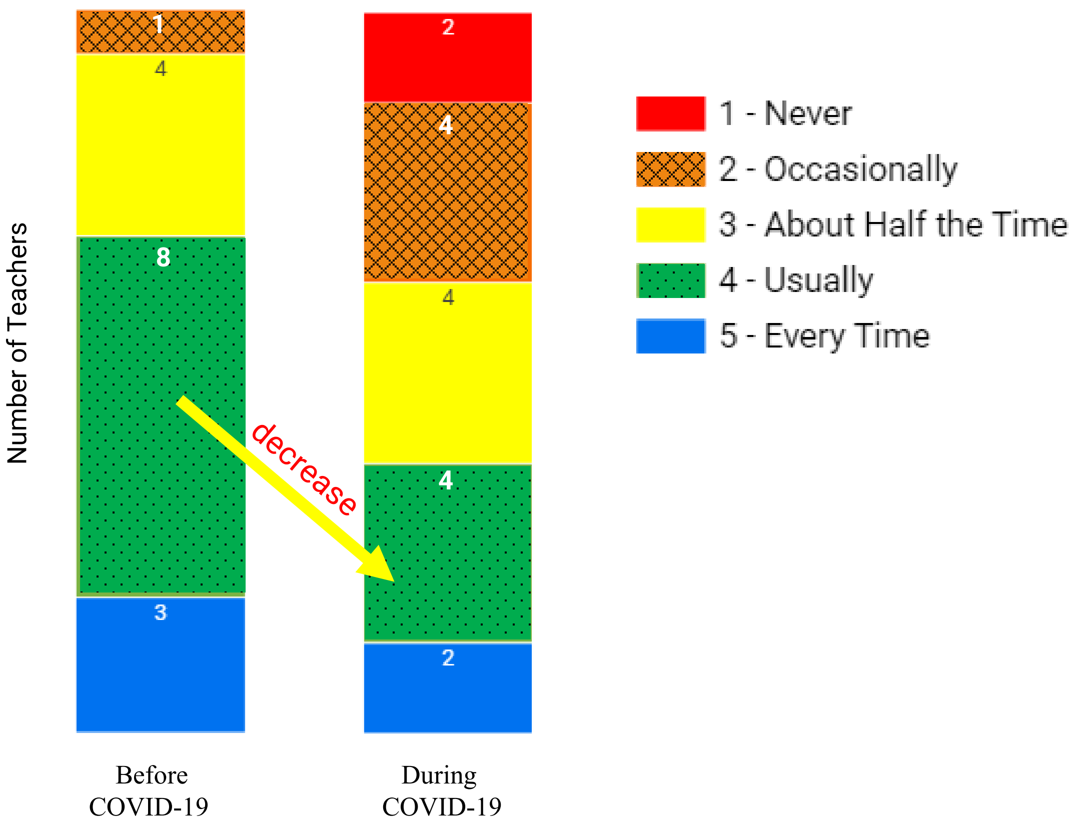

Figure 4. Frequency of Students Completing Activities with a Real-World Context Before and During COVID-19, as Reported by Teachers (n=16).

Question 5) How often did your students engage in STE lessons in a STEAM Lab or makerspace?

Before COVID-19, half of teachers (8 out of 16) reported that their students engaged in STE lessons in a STEAM Lab or makerspace "usually" and "every time" (Figure 5). Before COVID-19, each of these schools had an available STEAM Lab or makerspace. During COVID-19, this frequency dropped to only 1 out of 16 teachers reporting these frequencies while 15 out of 16 teachers reporting students "never" or "occasionally" engaged in a lab or makerspace.

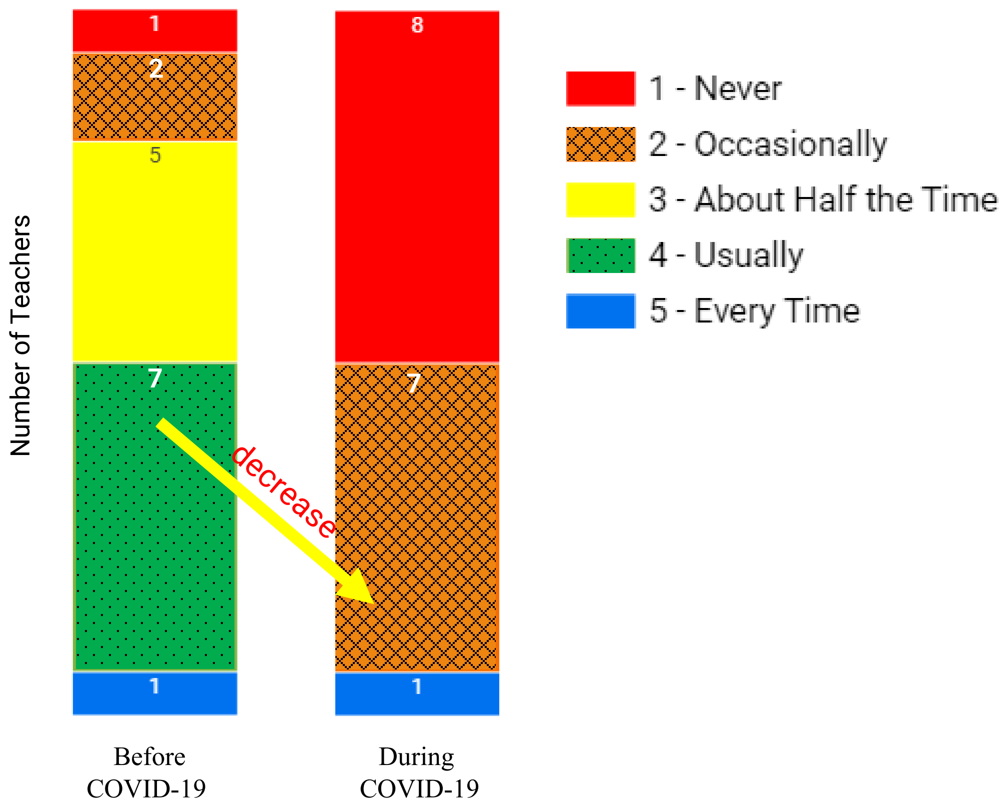

Figure 5. Frequency of Students Engaging in STE Lessons in a STEAM Lab or Makerspace Before and During COVID-19, as Reported by Teachers (n=16).

Qualitative Results

Qualitative analysis converged on 2 themes of results, as represented in Figure 6:

1) The COVID-19 pandemic *continued* to disrupt science, technology, and engineering teaching and learning.
2) Teachers recognized what was *missing* during the pandemic, namely student collaboration, hands-on investigations, and using their school's STEAM Lab.

Figure 6. Students working together before COVID-19 (left picture). No collaboration between students during COVID-19 (right picture).

Theme #1: COVID-19 continued to disrupt science, technology and engineering teaching and learning.

All 16 teachers in both school districts across grades preK - 5 indicated in their open-comment responses to the teacher survey that COVID-19 impacted their science teaching in various ways, not just at the beginning of the pandemic but through the 2020 - 2021 and 2021 - 2022 school years. Teachers who were interviewed also elaborated on their experiences about how COVID disrupted all teaching and learning, but especially STE. All six administrators indicated in their open-comment responses to the administrator survey that COVID-19 definitely impacted teaching and learning in their districts and some even discussed these impacts during their interview.

At the beginning of the pandemic when schools closed in March 2020, all teaching and learning pivoted to an all-remote, asynchronous model for these two school districts. Teachers in both school districts teamed up and coordinated themselves by grade level (and if applicable, across schools) to identify, share and deliver science lessons asynchronously. According to their survey open response comments or interview comments, teachers used Google Classroom, Canvas or direct email to parents and caregivers. Asynchronous lessons were designed to be as accessible and equitable as possible for young students and their caregivers at home, given the various computer skills and Internet access abilities of new remote learners (and their caregivers). Any hands-on science activities or assignments, if applicable, were designed to use readily available common household supplies.

From September 2020 to approximately March 2021, both school districts used a hybrid teaching and learning model for grades K – 5 in which cohorts of students were in-person for two days per week and fully remote the other three days per week, alternating by cohorts. Wednesdays were mostly dedicated to teachers' common planning times and virtual check-ins or extra help sessions with students and served as the transition day between cohorts. Preschool students in one district attended school in-person for the entire 2020 – 2021 academic year because social distancing space and time constraints were accommodated safely.

Science, technology and engineering units and lessons, if applicable, were delivered in-person when the students were in school and asynchronously for when the students were learning from home on their remote days. The following quotes are from four *different* 4th grade teachers but their experiences were generally shared by the other teachers in this study who taught science during the pandemic.

A 4th grade teacher provided examples of hands-on activities her students did at home:

> "For the kids that were remote, they would do some science, but again the depth of what we did was much different because it had to be something that was pretty easily accessible for parents to do at home and kids to do, mostly independent. I mean we did some, I do remember one time we sent home those little LED lights and batteries and the tape so they could make a circuit at home, and then we did a Zoom together and I kind of talked them through it. I remember, we sent them home a packet of seeds, so they could grow those at home and we could talk about those together."

Another 4th grade teacher referenced equitable access to basic supplies at home:

> "[one of the challenges during COVID-19 was] not necessarily having the supplies you need because, in order to do what you like to do or teach what you'd like to teach, even for an at-home assignment, there are those students who don't even have a printer. I've had students who don't even have a pair of scissors or a pencil. So I mean, you really do have to do everything on their Chromebooks because that's all that technically we gave them for remote work."

Finally, another 4th grade teacher leveraged online Mystery Science lessons for when students were remote but acknowledged that reading and math were the priority over science:

> "For science, when we were hybrid it was more like the in-person part. I tended to stick mostly with Mystery Science just because there were so many digital resources available that I could have the at-home students do, but when it came to doing the hands on activities, I would save those for the days that they were in school… I tried to keep it [home activities] fairly simple just because they would spend all their time on reading and math and then think that science was an afterthought like if I get to it, I'll do it."

During this hybrid model, COVID-19 social distancing constraints significantly transformed the physical spaces of schools, including classrooms, cafeterias, STEAM labs, gymnasiums, and other rooms. Teachers’ classroom desks, books, furniture and supplies were moved out to storage areas to accommodate the 6 feet social distancing requirement so that students’ desks would all fit in their classrooms. Teachers sometimes procured enough materials and supplies so that every student had what they needed, but this was additional work and cost. Public health restrictions throughout the pandemic impacted STE teaching and learning in particular because students were not allowed to be physically near each other, which is required for collaboration and teamwork.

For example, a 4th grade teacher wrote in her survey that she couldn’t engage her students in collaborative engineering design practices:

> “COVID made it difficult to engage in STEM activities because they couldn't share supplies. Usually I would have students work with partners or small groups to design a solution to a problem. They really couldn't do that when they had to stay 6 feet apart.”

A 5th grade teacher described her teaching accommodations due to COVID-19:

> “A lot of my lessons changed because I usually have students working with a partner or a group. With COVID concerns, I had to modify lessons so that students could work alone. I also did a lot less hands-on lessons because it takes too many supplies to give individuals the materials they needed to explore. I used a lot more short video clips, teacher demonstrations and paper and pencil tasks.”

Teachers also commented about how COVID impacted their students’ learning. A 1st grade teacher described what her students experienced during the early hybrid learning days when materials could not be shared:

> “Students had to do some experiments at home, alone or with a family member. When in school, they did not do experiments in groups. They have lost the practice of working together in groups. They did not share materials because they couldn't touch the materials that someone else touched.”

A kindergarten teacher described modified conditions for students’ learning:

> “Our classroom materials were removed to be able to fit student desks 6 feet apart. We were also unable to share hands-on materials. Therefore, students learned through observations, readings, and discussions. Some hands on craft projects were done as long as each student had their own pre-prepped materials.”

A 4th grade teacher explained how social distancing closed her school’s STEAM lab:

> “Our STEAM lab is kind of up in the air at the moment because things got moved around, it was used as a storage room last year during COVID when everybody had to be six feet apart and we didn't have room for furniture.“

When asked about her biggest teaching challenges during COVID-19, this 4th grade teacher referenced impacts due to both space and time COVID-19 restrictions:

> "Not being able to share certain supplies and not being able to be in close proximity with one another for long lengths of time, not having the space because you know we have to be distant, but also because of storage reasons. I think the lack of availability of time, space, supplies that's just been the biggest issue."

Administrators also contributed their thoughts about COVID's impact on teaching and learning, in both their survey open comment responses and in their interviews. First, administrators commented about the *impact of COVID-19 on teachers' teaching*. These assistant principals referred to reduced learning time as a consequence of teachers' increased remote and hybrid planning time:

> "The biggest impact of COVID on teaching science, technology & engineering would be time on learning of these subject areas. Planning and preparation for remote and hybrid learning was so time-consuming that it impacted the time directly teaching in these areas."

> "There has been a significant impact on the teaching and learning of science. With reduced classroom time, a heavier focus was placed on "closing the gap" with math, reading, and ELA as students returned."

Both assistant superintendents acknowledged an emphasis on ELA and math instruction and teaching/learning difficulties due to COVID-19:

> "Yes, it [COVID-19] has had a negative impact. Teachers are more focused on literacy and math, and it was difficult to provide direct instruction during remote or hybrid learning, as well as provide opportunities for collaboration and group learning."

> "Teachers are focusing on literacy and math during the pandemic. They were unable to do hands on work. More non-fiction was added to address science standards."

Second, administrators commented about the *impact of COVID-19 on students' learning*. These assistant principals from two different schools explained how hybrid/remote learning and less emphasis on teaching science have impacted student outcomes:

> "Hybrid and remote learning [due to COVID] especially impacted the ability for students to engage in hands-on lessons and experiments in science."

> "There has been less emphasis on science and less ability to provide hands on, collaborative experiences which has negatively impacted student outcomes."

Finally, both assistant superintendents reflected on how students were impacted directly:

> "Yes, it [COVID] has had a negative impact. Although teachers provided options, resources, links, etc., students really had to take some initiative to fully dive in. Students

were not exposed to as many concepts, experiment opportunities, lessons, etc. as they were prior to the pandemic."

"COVID prevented inquiry based hands-on experiences."

Theme #2: Teachers recognized what was *missing* during the pandemic, namely student collaboration, hands-on investigations, and using the school's STEAM Lab.

Several teachers commented on the lack of hands-on collaboration among students due to COVID-19 social distancing and time constraints. One 2nd grade teacher even shared how *distraught* she was about this loss:

> "It's amazing that when pre-COVID we're in a STEAM lab, those children who had those, I call [them] my little engineer minds, when they shine, they help those children who are so literal and can't think outside the box. And the collaboration, I mean I had some students who might struggle academically but put them in STEAM lab situation and they flourish and they feel that they're needed and they feel that they're helpful and they're helping their classmate. Perhaps their classmate is having trouble with an engineering activity, you know, like the one where they're protecting their head from the sun to create this hat. There are some children who just fell apart with that activity and those who struggle maybe academically, but they shine [in the STEAM Lab] and they were right in there, helping them [classmates] and then they will go around to each table, because they were done with their hat like that, and it was great they had no problem using materials. And they were helping other kids. I mean that's what made STEAM so wonderful as a teacher, opening eyes to see that and that's what's been, that's **the sadness of the COVID** what that has done, they're still creating and wonderful, but for them to go around table to table, desk to desk to help, it's more of now a verbal "well look what I did, look how I did this, how I did this…"

She continued to discuss student collaboration later in the interview:

> "I think the major impact is the hands-on collaboration with students working together. The curriculum stayed the same, but we had to improvise on the collaboration piece and what projects could be hands-on and what could not be hands-on that may have been previously a hands-on activity."

A 4th grade (former 3rd grade) teacher reflected on the collaboration that she misses for her students:

> "But it just didn't have that same togetherness, and that same cooperation, working together, solving problems, which is good and bad because some kids don't like doing that [laughing], and they want their own way, and they got their own way, because they were working on their own things but as a teacher, I liked seeing them struggle together and work together."

This 5th grade teacher noticed that students have not practiced working in groups since the pandemic started*:*

> "Students had to do some experiments at home, alone or with a family member. When in school, they did not do experiments in groups. They have lost the practice of working together in groups."

A 2nd grade teacher commented on students' reduced engineering experiences in her STEAM Lab as a result of the pandemic:

> "Students do not have the opportunity to involve in STEM activities, especially involving the engineering process, like they did when we visited the STEM Lab pre-pandemic."

This 2nd grade teacher confirmed that her school's STEAM Lab was not available:

> "Due to the hybrid model, we needed to split science and social studies and alternate. We also couldn't use the STEAM Lab and had to do science remotely with asynchronous videos of myself or another teacher showing the experiment."

One principal cited ongoing social distancing constraints for why students cannot use their STEAM Lab:

> "COVID had a huge impact on teaching of science. Remote and hybrid learning created great difficulty for teaching and learning. Our STEAM Lab has become an Innovation Lab, but students are not able to gather there due to space restrictions."

Two administrators in particular commented on the optimistic use of STEAM Labs:

> "I think it's beneficial if you do have that space, a STEAM lab, to be able to help you with the engineering process and concepts, but it kind of goes back to more of that problem and solution, and giving the students materials, giving them what the problem is and letting them try to explore the solution is the engineering…having the students have the freedom to do that ... and that's where the science and math come into play."

> "I also think that our outdoor spaces are going to become more integral to our STEAM education…I think it [STEAM Lab] has a place, but I just don't want it to be the destination."

In summary, the COVID-19 pandemic disrupted STE teaching and learning, both directly and indirectly. Teachers and administrators recognized what was *missing* during the pandemic, namely student collaboration, hands-on investigations, and using the school's STEAM Lab.

Discussion & Conclusion

Not only did COVID-19 abruptly disrupt education beginning in March 2020 but it has *continued* to disrupt and impact schools, students, parents/caregivers, and the educators that support them. In this study, the pandemic disrupted STE teaching and learning in terms of lost skills: unavailable STEAM Labs, less hands-on collaborative lessons, more focus on other subject areas and less instructional time for STE. In summary, the COVID-19 pandemic disrupted the STE curricula revision process, including STE teaching and learning and even prevented some from teaching STE content altogether.

However, the pandemic also disrupted the traditional *way* of teaching science and presented teachers with new instructional tools. Another term for a disruption that has a positive effect is "*disruptive innovation*". One 4th grade teacher added her own thoughts at the end of her interview about the trajectory of STEAM education in her classroom and COVID-19's "disruptive innovation". As teaching and learning return to "normal", she hopes that teachers reflect on what really worked during remote learning and incorporate those effective practices back into in-person instruction:

> "I'm impressed with educators and what we've been able to do in such a short amount of time, and I think that we should not walk away from what we learned when we were remote, because I think that was so valuable and when we think about how we have so many different types of learners out there, there are some learners that really did benefit from the remote learning. And there were some really good remote learning lessons. So I don't want to see us do an all or nothing or go from one model to another model without really reflecting on what worked, so what did work with the remote learning and how can we bring that into today's world?"

When teachers embrace new content knowledge and a pedagogical shift that supports the new frameworks, students directly benefit. These students learn how the real-world operates in which they are simultaneously immersed into their work as mathematicians, scientists, engineers, and artists. These students ask questions, define problems, develop and use models, plan and carry out investigations, analyze and interpret data, use math and computational thinking, construct explanations, design solutions, engage in argument from evidence, and communicate information, just as professional scientists and engineers do.

For these teachers and their students, school begins to look more like the integrated STEAM archway (Figure 7) and less like disjointed or incomplete silos (Figure 8).

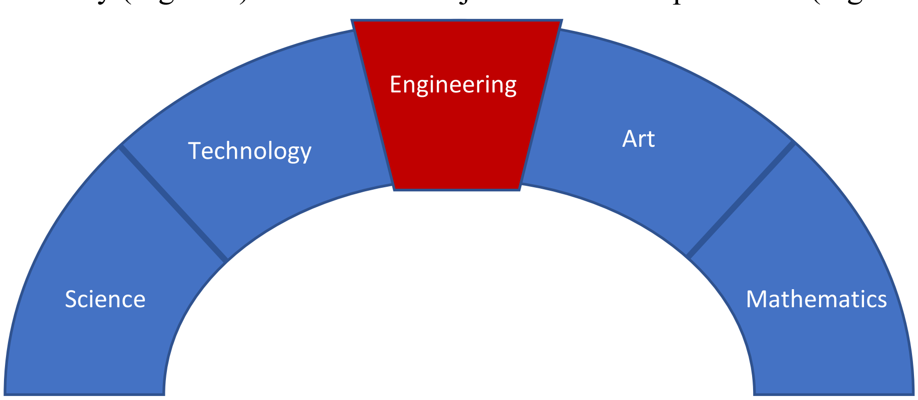

Figure 7. STEAM archway with Engineering as the keystone.

Figure 8. Science and mathematics taught separately in silos.

This STEAM archway (Figure 7) is an analogy to integrated STEAM education and extends Rodger Bybee's model [4] into a 3-dimensional structure. The keystone is the most important structural piece of any arch because it distributes weight at the top of the arch through the sides of the arch to the cornerstone pieces, which are anchored in the ground, sometimes only by their own weight. The weight of the keystone supports the adjacent pieces, while these pieces then support the remaining cornerstone pieces to make the entire arch stable. Without the keystone, the arch collapses. Without engineering, technology and art fall away, and the connections between science and mathematics are lost. Without engineering, science and math may stand on their own as the cornerstone pieces, but they remain isolated (as "silos" according to Bybee [4]) (Figure 8). When engineering is authentically and genuinely integrated into STEAM education, students practice science and engineering together, using technology as a tool and art as a form of communication and expression to complete their integrated journey between science and mathematics.

Next steps would be to engage teachers in continuous, embedded professional development that focuses on engineering pedagogy and engineering practices, with engineering as the keystone to help *integrate* STEAM education. In addition, researchers should follow the short-term and long-term integration of engineering into elementary education to study student outcomes well beyond the COVID-19 pandemic.

Although this study's focus was not directly on students' experiences, future research would undoubtedly include direct measures of students' science and engineering practices and curricula performance. Considering that the distinguishing feature of this study was to focus on engineering as the "keystone" to truly integrated STEAM education and improved teacher and student learning outcomes, the "E" in STEAM certainly deserves more curricula emphasis in our current elementary school system of education. Perhaps now the teachers in this study and elsewhere will be able to finish their transition to aligning to the new STE curriculum frameworks now that the COVID-19 pandemic has passed. As demonstrated in the literature and in this study, engineering certainly can be leveraged as a catalyst to motivate the integration of authentic STEM disciplines to "STEAM up" elementary education.

Acknowledgements

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Appendix A
Teacher Survey Questions

7. Frequency of Science Teaching Prior to COVID-19 *

Prior to COVID-19, which BEST described your science teaching? Select only 1 answer.

- (◉) I taught science all or most days, every week of the year.
- ( ) I taught science every week, but typically not every day of the week.
- ( ) I taught science some weeks, but typically not every week.
- ( ) I did not teach science.
- ( ) Other: ______

2. Frequency of Science Teaching During COVID-19 *

During the most recent 2020 - 2021 academic year, which BEST described your science teaching? Select only 1 answer.

- ( ) I taught science all or most days, every week of the year.
- ( ) I taught science every week, but typically not every day of the week.
- ( ) I taught science some weeks, but typically not every week.
- ( ) I did not teach science.
- ( ) Other: ______

3. COVID-19 Impacts on Teaching STE *

How has the COVID-19 pandemic impacted YOUR TEACHING in science, technology & engineering? This question focuses on your instructional practices and pedagogical approach, including any adjustments or modifications you made in your instructional delivery, planning, preparation, tools, teaching environment, and actual curricula taught, both at the beginning of (March - June 2020) and during the COVID-19 pandemic (September 2020 - June 2021). Please explain in a few sentences or paragraphs (your choice).

Your answer ______

4. COVID-19 Impacts on Student Learning STE *

How has the COVID-19 pandemic impacted YOUR STUDENTS' LEARNING in science, technology & engineering? This question focuses on your students' learning, their learning environment, tools, and actual student outcomes (what do you know that they learned or did not learn), both at the beginning of (March - June 2020) and during the COVID-19 pandemic (September 2020 - June 2021). Please explain in a few sentences or paragraphs (your choice).

Your answer

6. BEFORE COVID-19: Student Engagement during Science Instruction *

Before COVID-19, during elementary STEM instructional meetings (e.g. class periods, etc.), how often did your students.... Select 1 response per row.

	1 - Never	2 - Occasionally	3 - About Half the Time	4 - Usually	5 - Every Time
a. Develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations).	○	○	○	○	○
b. Work in small groups.	○	○	○	○	○
i. Complete activities with a real-world context.	○	○	○	○	○
o. Engage in science, technology and/or engineering lessons in a STEAM Lab or makerspace.	○	○	○	○	○

7. 2020-2021 academic year: Student Engagement during Science Instruction *

During the 2020-2021 academic year with COVID-19, during elementary STEM instructional meetings (e.g. class periods, etc.), how often did your students.... Select 1 response per row.

	1 - Never	2 - Occasionally	3 - About Half the Time	4 - Usually	5 - Every Time
a. Develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations).	○	○	○	○	○
b. Work in small groups.	○	○	○	○	○
i. Complete activities with a real-world context.	○	○	○	○	○
o. Engage in science, technology and/or engineering lessons in a STEAM Lab or makerspace.	○	○	○	○	○

Section 11. Participant Demographics

This is the last section of the survey. Only 4 more easy questions!

1. Which gender do you identify with? *

- ○ Man
- ○ Woman
- ○ Non-Binary
- ○ I prefer not to answer
- ○ Other: ____________________

2. Are you of Hispanic or Latinx origin? *

- ○ Yes
- ○ No

3. What is your race? Select all that apply. *

	Yes	No
American Indian or Alaskan Native	◯	◯
Asian	◯	◯
Black or African American	◯	◯
Native Hawaiian or other Pacific Islander	◯	◯
White	◯	◯
Other	◯	◯
I prefer not to answer	◯	◯

4. In what year were you born? Enter a whole number (for example 1971). *

Your answer

Appendix B
Administrator Survey Questions

11. COVID-19 Impact on Teaching *

How has the COVID-19 pandemic impacted YOUR ELEMENTARY TEACHERS' teaching of science, technology & engineering? This question focuses on their instructional practices and pedagogical approach, including any adjustments or modifications they may have made in their instructional delivery, planning, preparation, tools, teaching environment, and actual curricula taught, both at the beginning of and during the COVID-19 pandemic. Please explain in a few sentences or paragraphs (your choice).

Your answer

12. COVID-19 Impact on Learning *

How has the COVID-19 pandemic impacted YOUR DISTRICT's or SCHOOL's STUDENTS' LEARNING in science, technology & engineering? This question focuses on students' learning, their learning environment, tools, and actual student outcomes (what do you know that they learned, student artifacts), both at the beginning of and during the COVID-19 pandemic. Please explain in a few sentences or paragraphs (your choice).

Your answer

Section 6. Participant Demographics

This last section of the survey asks for information about you.

1. Which gender do you identify with? *

- ○ Man
- ○ Woman
- ○ Non-Binary
- ○ I prefer not to answer
- ○ Other: ____

2. Are you of Hispanic or Latinx origin? *

- ○ Yes
- ○ No

3. What is your race? Select all that apply. *

	Yes	No
American Indian or Alaskan Native	○	○
Asian	○	○
Black or African American	○	○
Native Hawaiian or other Pacific Islander	○	○
White	○	○
Other	○	○
I prefer not to answer	○	○

4. In what year were you born? Enter a whole number (for example 1971).

Your answer

A copy of your responses will be emailed to the address you provided.

Back   Submit   Page 6 of 6   Clear form