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Abrupt Shift or Caught Off Guard: A Systematic Review of K-12 Engineering and STEM Education’s Response to the COVID-19 Pandemic

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Abstract

In the past hundred years, there have been a number of pandemics that have affected the entire world, including the 1918 H1N1 influenza pandemic, the 1957 H2N2 influenza pandemic, and the 2009 H1N1 influenza pandemic. While responses to the most recent H1N1 influenza pandemic remained local, the COVID-19 pandemic, on the other hand, resulted in long-term school closures all around the world, prompting a sudden shift to distant education by compelling K-12 educators and students to do so. The purpose of this study is to find out how K-12 education studies reacted to the sudden shift in supporting engineering and STEM (science, technology, engineering, and mathematics) education during the COVID-19 pandemic. To accomplish this goal, we conducted two separate searches in different databases and reviewed 25 articles. These articles were classified into four categories: (1) adaptation to online learning and the effects of a sudden shift, (2) implementing new strategies and tools, (3) STEM education in informal learning environments, and (4) teacher professional development. Our analysis indicated that engineering and STEM education research primarily focused on higher education during the COVID-19 pandemic. The limited number of studies examining K-12 engineering and STEM first investigated the adaptation to online learning by utilizing various resources that elementary and secondary teachers could easily access. Blended learning, flipped learning, and maker pedagogy were encouraged in K-12 engineering and STEM studies. Movies were the most commonly used tool in K-12 engineering and STEM studies. It is encouraging that studies also examined informal learning contexts (outreach initiatives, museums) and inequities in STEM and engineering education. However, the small number of studies in each category reminds us that there is still a lot of work to be done in terms of the future of K-12 engineering education, especially considering that distant education may become a permanent part of K-12 education.

Keywords

pandemic, K-12, engineering education, STEM education

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Abrupt Shift or Caught Off Guard: A Systematic Review of K-12 Engineering and STEM Education's Response to the COVID-19 Pandemic

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Abstract

In the past hundred years, there have been a number of pandemics that have affected the entire world, including the 1918 H1N1 influenza pandemic, the 1957 H2N2 influenza pandemic, and the 2009 H1N1 influenza pandemic. While responses to the most recent H1N1 influenza pandemic remained local, the COVID-19 pandemic, on the other hand, resulted in long-term school closures all around the world, prompting a sudden shift to distant education by compelling K-12 educators and students to do so. The purpose of this study is to find out how K-12 education studies reacted to the sudden shift in supporting engineering and STEM (science, technology, engineering, and mathematics) education during the COVID-19 pandemic. To accomplish this goal, we conducted two separate searches in different databases and reviewed 25 articles. These articles were classified into four categories: (1) adaptation to online learning and the effects of a sudden shift, (2) implementing new strategies and tools, (3) STEM education in informal learning environments, and (4) teacher professional development. Our analysis indicated that engineering and STEM education research primarily focused on higher education during the COVID-19 pandemic. The limited number of studies examining K-12 engineering and STEM first investigated the adaptation to online learning by utilizing various resources that elementary and secondary teachers could easily access. Blended learning, flipped learning, and maker pedagogy were encouraged in K-12 engineering and STEM studies. Movies were the most commonly used tool in K-12 engineering and STEM studies. It is encouraging that studies also examined informal learning contexts (outreach initiatives, museums) and inequities in STEM and engineering education. However, the small number of studies in each category reminds us that there is still a lot of work to be done in terms of the future of K-12 engineering education, especially considering that distant education may become a permanent part of K-12 education.

Keywords: pandemic, K-12, engineering education, STEM education

Introduction

After several years of battling the COVID-19 pandemic, schools around the world have begun to reopen, and countries are constantly updating their school closure policies. After the H1N1 influenza pandemic of 1918, the H2N2 influenza

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pandemic of 1957, and the H1N1 influenza pandemic of 2009, it is vital to remember that this is not our first encounter with a pandemic. In Michigan (USA), the most recent influenza pandemic resulted in 567 school cancellations (Dooyema et al., 2014). Mexico City closed all schools on April 24, 2009, and different states in the United States have developed different standards for school closures (Klaiman et al., 2011). Studies during the latest influenza discussed the effects of short-term school closures (Thorrington et al., 2017; Tsai et al., 2017), the impacts of vaccination (Gicquelais et al., 2016), and support programs for school nurses (Rebmann et al., 2016).

The COVID-19 pandemic forced the closure of schools for an extended period of time. The education community's response was unique in that it shifted attention to students and instructors around the world. Naydenova and Chernev (2020) stated that "the global problem COVID-19 presents humankind with new and unknown things" (p. 260). Radu et al. (2020) referred to this change as "online teaching and learning has gone from a choice to a need" (p. 206) in another study. When online learning became the only option, scholars began to investigate students' and teachers' reactions to the change.

Two students from Utah, USA, were invited by Marstaller (2020) to write about their experiences during the lockdown. Bulgarian high school students were explored by Naydenova and Chernev (2020), whereas Romanian high school students were investigated by Radu et al. (2020). Duckworth et al. (2021) studied high school students in a district where parents selected between face-to-face and online courses. According to Duckworth et al., students who attend face-to-face classes perceive themselves to be in a better social, emotional, and academic state than their peers who take classes online. In another study, Aldon et al. (2021) evaluated instructors' practices in mathematics education in four countries and found different strategies that can be employed in online learning.

Similarly, engineering education programs dealt with obstacles and prepared for the shift to engineering education. Estrada and Prasolova-Førland (2022), for example, discussed how to run an extended reality lab in Norway. Singhal et al. (2020) investigated how to use various mobile and digital tools to aid students' engineering learning. In Poland, Ożadowicz (2020) looked into how to enhance active learning among automation engineering students. Nogales-Delgado et al. (2020) focused on students' active learning in a chemistry lab in Spain.

In engineering education, encouraging students' active learning through the use of various digital technologies has a long history. Virtual labs were used as a method to achieve this goal in engineering education. According to Simoff et al. (2002), virtual labs are an "advanced strategy" (p. 29) that encourages the use of digital tools. Simoff et al. offer a platform for engineers and students to cooperate on projects and conduct laboratory experiments by exchanging information electronically on a variety of activities. Usman et al. (2021) reviewed virtual lab studies and argued that virtual lab media can help support students' scientific understanding through distance learning. Electrical engineering studies (Balid et al., 2012; Kollöffel & de Jong, 2013; Simoff et al., 2002) have looked into how virtual experiments might help students learn. In addition, engineering education studies present virtual design studios that help the design process (Erden et al., 2000; Koutsabasis & Vosinakis, 2012).

Virtual studios (Erden et al., 2000; Koutsabasis & Vosinakis, 2012) or virtual labs (Balid et al., 2012; Kollöffel & de Jong, 2013; Simoff et al., 2002) have long been used in engineering education to promote distance learning. Because of the sudden shift during the COVID-19 pandemic, K-12 educators and students were forced to use online learning. The purpose of this study is to examine how K-12 education studies reacted to the sudden shift in support for engineering education during the COVID-19 pandemic. K-12 engineering education is explored in conjunction with science, technology, engineering, and mathematics (STEM) education studies in this research. STEM education is presented as an important approach to supporting engineering in K-12 education (National Research Council, 2011). Several studies undertaken during the pandemic (e.g., Baptista et al., 2020; Gilchrist et al., 2021) predominantly focused on STEM education while exploring connections to K-12 engineering education. Baptista et al. (2020), for example, examined how teachers "adapt, and implement a STEM activity in the context of a pandemic" (p. 1044). Gilchrist et al. (2021), on the other hand, investigated pandemic awareness when adopting a STEM program.

Method

To understand engineering education during the COVID-19 pandemic, we conducted a systematic review in two different phases (Furtak et al., 2012). We searched the abstracts for "engineering" and crossed it with "COVID OR pandemic OR emergency remote" and "student" in the first phase. We added students because our major goal is to identify K-12 implementations. The initial phase was restricted to the Web of Science (WoS) and Scopus databases. In the second phase, we added more keywords, including "K-12 STEM OR STEM education OR engineering education" in the abstracts and crossed it with "COVID OR pandemic OR emergency remote." The goal of the second phase was to expand our search by including STEM education studies. In the second phase, we also added more databases, and the second expanded search was carried out in WoS, Scopus, ERIC, APA PscyInfo, and JSTOR databases.

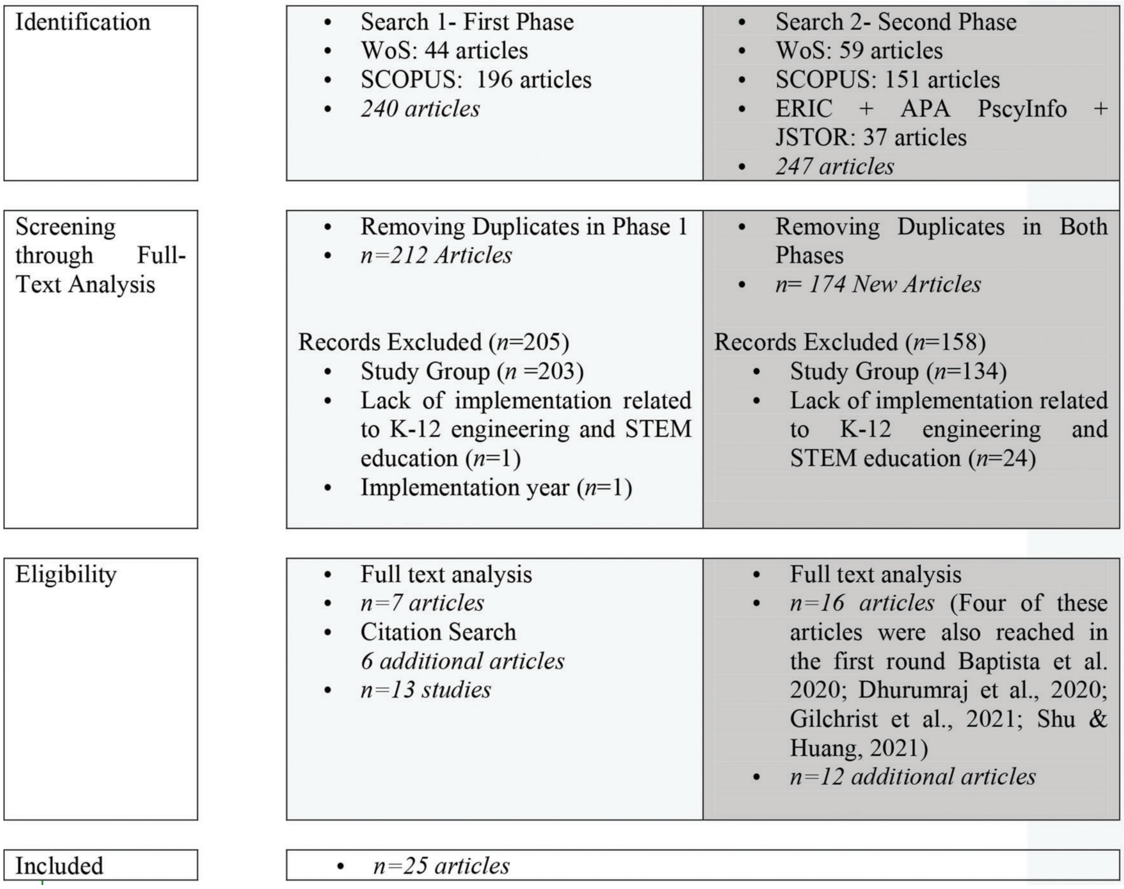

Figure 1. PRISMA flow chart for inclusion of studies.

Table 1
Selection criteria during screening.

Exclusion criteria	
Study group	Faculty members (e.g., Morelock et al., 2020), undergraduate students (e.g., Singhal et al., 2020), pre-service teachers (e.g., Yllana Prieto et al., 2021)
Lack of implementation related to K-12 engineering and STEM education	Review studies (e.g., Deák et al., 2021) or missing implementation (e.g., Tyagi et al., 2021)
Implementation year	Implementation before COVID-19 pandemic (e.g., Songer & Recalde, 2021)

In our review, we only examined articles published in English in both phases (Ping et al., 2018). The search in the WoS database was limited to educational research in both phases, while that in Scopus was limited to social sciences and that in JSTOR was limited to education. The first phase yielded 212 articles after deleting duplicates, and the second phase yielded 174 new articles (see Figure 1). The first phase took place in August 2021 and the second in February 2022.

We defined our selection criteria (Anwar et al., 2019) and reviewed the full texts of 386 papers during the screening process (see Table 1). In this process, we first reviewed the participant group to exclude studies missing connections to K-12 settings. We excluded studies that were conducted with faculty members (Morelock et al., 2020; Vermund et al., 2008) or undergraduate students (Estrada & Prasolova-Førland, 2022; Nogales-Delgado et al., 2020; Ożadowicz, 2020; Singhal et al., 2020) and pre-service teachers (Yllana Prieto et al., 2021).

Furthermore, studies that did not include implementation related to K-12 engineering and STEM education were eliminated. Deák et al. (2021) reviewed inquiry-based approaches used during the pandemic. Tyagi et al. (2021) looked into the impacts of using mobile phones during the pandemic in another study. Both of these studies were excluded due to the lack of implementation in K-12 settings. On the other hand, having a K-12 implementation was not enough to include a study in the review. We also looked at when the implementation took place. Songer and Recalde (2021) made connections with pre-college engineering in another study. The authors finished the implementation before the pandemic and made reference to the pandemic as an implication. As a result, that study was excluded from the review. The screening process was an iterative cycle, and Figure 1 presents the final number of articles reached after screening.

The authors conducted a thematic analysis after determining which studies would be included in the review (Passow & Passow, 2017). Each author reviewed each study several times during this process to ensure that they thoroughly understood the focus, methodologies, strategies, tools, and outcomes (Braun & Clarke, 2006) with an emphasis on STEM and engineering education. The evidence gathered during the eligibility was compared between authors, and the studies that met the inclusion criteria were divided into four categories: (1) adaptation to online learning and effects of abrupt shift; (2) implementing new strategies and tools; (3) STEM education in informal learning environments; and (4) teacher professional development (PD). Table 2 includes the definitions of these categories as well as the studies under each category.

Results

Our systematic review of K-12 engineering and STEM education studies identified a small number of articles during the COVID-19 pandemic. The majority of the articles were conducted in higher education during both phases. Researchers focused on adaptation, implementation, and offering PD while conducting implementations in K-12 settings. With 10 articles, the USA was the leading country in our analysis. South Africa came in second with two articles. Only one article was found for each of the remaining countries (Canada, Spain, Taiwan, Switzerland, Romania, Zambia, Qatar, Portugal, India, the United Arab Emirates [UAE], Indonesia, Hong Kong, and Turkey) in our analysis. Figure 2 presents category-based distributions and how the studies are distributed among different countries under each category.

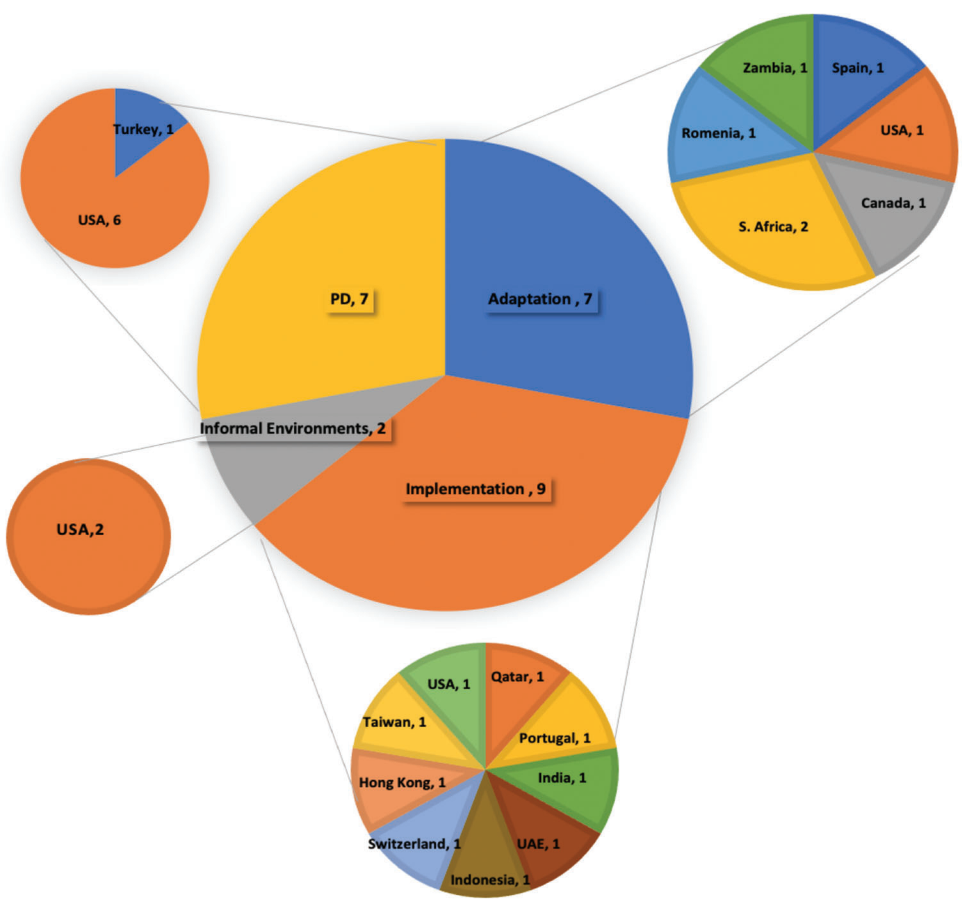

Figure 2. Country distribution under each category.

Table 2
Categories of K-12 engineering education studies during the pandemic period.

Category: foci of the study	Description of the category	Studies involved in the category
Adaptation to online learning and effects of abrupt shift	Examining the perspectives and experiences of practitioners during online education	Beardsley et al. (2021) (Spain); Code et al. (2020) (Canada); Dhurumraj et al. (2020) (South Africa); Makamure & Tsakeni (2020) (South Africa); Panisoara et al. (2020) (Romania); Kang et al. (2021) (USA); Sintema (2020) (Zambia)
Implementation of teaching strategies and tools	Creating a procedure for introducing online learning or adapting traditional curriculum and resources to virtual platforms	Abouhashem et al. (2021) (Qatar); Baptista et al. (2020) (Portugal); Charania et al. (2021) (India); ElSayary (2021) (UAE); Haryadi et al. (2021) (Indonesia); Huang et al. (2022) (Hong Kong); Rodríguez et al. (2021) (Switzerland); Shu & Huang (2021) (Taiwan); Wright & Bartholomew (2020) (USA)
STEM education in informal learning environments	Developing and offering new instructional designs for remote engineering and STEM education in informal settings	Gilchrist et al. (2021) (USA); Kilty et al. (2021) (USA)
PD	Explaining the PD provided to instructors during the pandemic in order to assist teachers in making the transition from face-to-face to online instruction	Aykan & Yildirim (2022) (Turkey); Benitz & Yang (2021); Chen & Cao (2022) (USA); Gordy et al. (2021) (USA); Kier & Johnson (2022) (USA); Larson & Farnsworth (2020) (USA); Wallace et al. (2021) (USA)

Table 2 categorizes each article according to its research topic. It is worth noting that, depending on its content, an article may fall into more than one category. In addition, the description of categories may have connections. We classified these studies into the appropriate groups based on their major objectives.

Adaptation to Online Learning and Effects of Abrupt Shift

During the COVID-19 outbreak, a considerable amount of research was conducted to find out STEM teachers' ideas as they shifted to distant education. Researchers were particularly interested in how teachers dealt with the drawbacks of online education as well as the strategies teachers employed to enhance students' enthusiasm and effectiveness in online teaching and learning. The impact of the COVID-19 pandemic lockdown and online teaching on technology education (TE) teachers' teaching practices, which are primarily focused on hands-on practical teaching and learning in traditional educational environments, was investigated by Code et al. (2020). Curriculum, equity and access, motivation, effectiveness, and sustainability were the five primary components of online education on which TE teachers focused. Overall, TE teachers stated that their capacity to facilitate hands-on development decreased after transitioning to online education due to unequal student access to tools, materials, and resources, all of which reduced student motivation and engagement.

Panisoara et al. (2020) investigated STEM teachers' problems and challenges with online education, as well as the impact of perceived risks on students' capacity to satisfy fundamental educational needs in each STEM discipline. The authors used students' participation in online learning activities as a mediator variable and school contexts as a control variable to achieve this purpose. As a consequence, both groups agreed that there is a significant correlation between technological and pedagogical perceived concerns caused by entirely online education. Teachers agreed that there is a substantial link between technological perceived threats and pedagogical perceived threats produced by exclusively online education. Pedagogical perceived risks and students' academic success have varying degrees of impact among STEM subjects. For instance, pedagogical perceived risks had the greatest negative influence on academic achievement in chemistry. But, there was not a statistically significant relationship in informatics, biology, or physics.

On the other hand, Beardsley et al. (2021) looked at how teachers' motivation and competencies in using digital tools for education have evolved since the pandemic began. For the data collection, the researchers surveyed primary and secondary in-service teachers at the beginning of the pandemic lockdown and the following semester. The authors also analyzed teachers' tweets and interview replies acquired following the lockdown. Although teachers expressed some concerns (e.g., a time or health issue, technological limitations, ineffectiveness of students' evaluation) about using digital technology in their courses, throughout the online education process, teachers' motivation to advance their teaching with digital technology increased.

Dhurumraj et al. (2020) aimed to identify teachers' STEM teaching transition from face-to-face to remote education. The Technological Pedagogical Content Knowledge (TPACK) was the theoretical framework for the study. The researchers looked at teachers' views on extending the educational approach to STEM education using virtual digital platforms during the COVID-19 pandemic lockdown in South Africa. The participants who took a web-based survey stated that they were quite confident in embracing virtual digital platforms to provide instruction to learners. Teachers overwhelmingly endorsed the use of information and communication technology (ICT) tools as a significant component of online teaching and learning. They also indicated insecurities about their overall professional competency in implementing online teaching and learning, as well as a lack of professional assurance in putting online teaching approaches into effect on virtual digital platforms. The conclusion of the study was the necessity of providing sustainable teacher PD on the use of digital resources. The TPACK framework was also utilized by Kang et al. (2021) to investigate how instructors' pedagogical strategies for STEM education evolved during and after remote teaching. Kang et al. emphasized the importance of providing additional support to teachers as they transition to online learning.

Makamure and Tsakeni (2020) investigated a method to improve the relevance and effectiveness of mathematics and science education. They concentrated on the teaching and learning of STEM lessons that highlight technical abilities, virtual learning environments, and online remote education in particular. Based on their interviews with STEM teachers, the authors concluded that, despite the hurdles, the utilization of online platforms for teaching and learning is conceivable. They also found the following factors hampered the successful use of online platforms in Zimbabwe: limited virtual tools (especially deficiency in internet connection), energy deficiency in homes and schools, and not having a mobile device. The authors also claimed that online STEM education caused inequity between those who could and could not afford it, because online teaching and learning need a significant investment in infrastructure and devices to enable connectivity. In another study conducted in Zambia, Sintema (2020) suggested that students who do not have the essential resources to follow remote education may fail national assessments.

Implementation of Teaching Strategies and Tools

Various studies at the K-12 education have already been published during the pandemic, analyzing the views of teachers, students, and parents on the challenges of remote learning. Nevertheless, empirical evidence on the application of online engineering or STEM education at the K-12 level is sparse. According to our search, only nine publications present an implementation strategy and/or tools for supporting engineering or STEM education in online platforms. In these studies, researchers sought a way to use instructional methods in virtual platforms. For example, Haryadi et al. (2021) integrated the blended learning model with the STEM learning approach (STEM-BL) to help high school students improve their high-level thinking abilities on physics content. The STEM learning approach includes steps such as live events using STEM, self-paced learning, assessment, and collaboration using STEM. The authors offered this approach as an alternative to blended learning, and as a result, they revealed that STEM-BL facilitated students' higher-level thinking abilities in comparison to the higher-level thinking abilities of students who received blended learning only. The main conclusion of these results is that STEM-BL can be utilized during a pandemic to improve high-quality perceptions, notably in problem-solving and design.

In another study, ElSayary (2021) worked with middle school teachers to monitor their practices of implementing a new lesson plan supporting STEM integration in a blended learning setting. That study also examined teachers' views of the implementation process. During the implementation, students used Zoom to present their projects and discuss ideas as they worked on completing the design. The results of the study showed that there is a correlation between the ability of teachers and students to use technology and the learning setting. Furthermore, the participant teachers stated that incorporating the reflective practice model into a blended learning approach tends to develop a diverse learning atmosphere in which individual needs and expectations are fulfilled. They also emphasized the significance of assessments that were designed to support students' learning.

Physics teachers' perspectives on the efficacy and difficulties of online learning, as well as teachers' online STEM teaching techniques, were revealed by Baptista et al. (2020). Before the COVID-19 pandemic started, these teachers participated in a STEM research project that revealed the role of STEM activities in students' understanding, motivation, and interest in choosing STEM careers. The STEM activity was developed by the project team and the teachers based on the principles of the STEM integration framework (STEM content integration, choosing a daily life problem, and inquiry-based learning). Physics teachers implemented the STEM activity via online platforms as synchronous or asynchronous. Due to the unplanned pandemic lockdown, teachers were forced to change the STEM activities that students could do at home. The findings show that conducting online STEM activities has an impact on students' learning. There were also challenges that teachers had to overcome during STEM activities.

Rodríguez et al. (2021) and Shu and Huang (2021) advocated that technologies for improved human–computer interaction employing augmented and virtual reality (AR/VR) have shown significant promise in helping STEM education and learning when remote learning became a necessity. Rodríguez et al. (2021) offer a freely accessible website with interactive AR applications. The AR application supported teachers and other parties in creating interactive content for their courses and hands-on experiences for their students, in face-to-face or online STEM lessons. Shu and Huang (2021), on the other hand, conducted a study to examine if VR software can improve teachers' STEM implementations during online education. The experimental setting consisted of one control and two experimental groups (VR group and VR + STEM approach group). Among these groups, control group students did not receive a Maker curriculum, while the VR group received a Makerspace with VR support. Additionally, the VR + STEM approach group took STEM-focused Maker lessons. The Maker lessons included Makerspace, 3D modeling, 3D printing, Webduino single-board microcontrollers and sensors, programming, and a Maker work built-in course. For VR support, the researchers used Google Expedition. The findings suggest that VR groups outperformed control group students, that the Maker course boosts students' Maker self-efficacy, and that STEM-focused education had a substantial effect on students' performance. Although the authors did not elaborate on how VR groups worked remotely during the pandemic, their arguments indicated that VR technology could be an effective facilitator for students to learn individually and to increase motivation.

Huang et al. (2022), on the other hand, claimed that STEM education at the K-12 level has been adversely affected by the COVID-19 pandemic. In order to transfer effective STEM education to pandemic conditions, they developed and implemented a transdisciplinary STEM curriculum. Multi-model video techniques were used in the new curriculum to support learning materials and involve learners in the learning process. The authors used the emphasize, define, ideate, prototype, test methodology as a design approach. The curriculum was supported with a number of different videos due to pandemic conditions, which led to a lack of group work and limited class time. The use of videos is also underlined in other studies. Wright and Bartholomew (2020) included short anecdotes from teachers about how they used videos and other technology to aid in the design process.

Abouhashem et al. (2021) created an interactive STEM-based instructional lesson for middle and high school students. Within three sections, the lesson was designed to contain both synchronous and asynchronous exercises: introductory, scientific, and concluding. While the introductory and concluding sessions focused mostly on previewing or recapping the daily lectures, the scientific sessions (synchronous and asynchronous) were the foundation of the daily curriculum, where students gained scientific knowledge via hands-on experiences. In that study, authors used various tools (Microsoft Teams, videos, PowerPoint, Kahoot, and Powtoon). Problem solving and creative thinking were included in the lesson activities. At the end of the lesson, students were required to construct a design product, which they presented to a panel of experts.

Charania et al. (2021) investigated the link between past engagement with information technology and constructive use of technology during the pandemic lockdown as well as the teaching and learning strategies utilized by teachers to integrate ICT during the lockdown. The information acquired through interviews with master teachers, teachers, and volunteer students was utilized to better understand the function of an integrated approach to technology in education when it is employed in problem-based learning with ICT throughout online education. Teachers said they communicated with students using various technologies such as instant messaging apps (WhatsApp) and video conferencing tools. They also discussed the advantages and drawbacks of online education. Almost all of the teachers expressed an interest in continuing to use instant messaging services after the lockdown. Another important finding of the research is that teachers who incorporated more information technology activities into their instructional design prior to the lockdown were more likely to use project-based learning. The authors stressed the importance of practice-based continuing PD for teachers.

STEM Education in Informal Learning Environments

A number of scholars have also identified distinct approaches to developing new STEM education models. During the COVID-19 pandemic, for example, Kilty et al. (2021) expressed concerns about the limitations of online learning in STEM education. As a result, three undergraduate students (a physics major, a computer engineering major, and a science pre-service teacher) created and implemented a series of STEM outreach lessons for eighth-graders. The purpose of these classes was to participate in inquiry or to solve an engineering challenge related to the topic. The undergraduate team planned and presented outreach lessons to students using hands-on inquiry through a radio occultation experiment based on national physical science standards. After returning from pandemic lockdown, the undergraduate students explored their choices for implementing their lesson ideas. These choices included that everyone in the classroom would attend in person, students would attend in person and the undergraduate team would attend remotely, half of the classroom would attend in person and the other half would attend remotely, everyone would attend remotely and synchronously, and everyone would attend remotely and asynchronously. The findings of this study indicate that instructional preparation should be rigorous and can be time-consuming. As a result, combining diverse learning and teaching scenarios allows educators to deliver the intended content more effectively, and students can benefit from a variety of learning contexts.

In a context-specific environment inside a STEM outreach program, Gilchrist et al. (2021) created a curriculum to help middle school students enhance their problem-solving skills, which are presented as a subset of their computational thinking and mathematical thinking practices. The authors state that data science-based STEM programs can improve student math practices and computational thinking. In the study, students were also given the opportunity to work on a STEM challenge, which allowed them to deepen their knowledge of STEM topics and practice their skills. After the COVID-19 pandemic outbreak, the Pandemic Awareness Outreach curriculum was included in the computational thinking skills.

Teacher Professional Development

The unexpected emergence of the COVID-19 pandemic has once again revealed to the entire globe how unprepared we were for rapid adaptation to new situations in a variety of areas, most notably education, where we shifted from traditional teaching and learning methodologies to remote teaching. As a result, scholars need to find ways to contribute to the global effort while the world tries to keep up with the new normal. According to studies conducted during the pandemic, it is difficult to transition from face-to-face to virtual education (Giovannella et al., 2020; Zaharah & Kirilova, 2020). Even teachers who previously stated that they were comfortable incorporating technology into their practices may struggle to adjust to teaching remotely via an online platform. Researchers offered expert support for various needs to help teachers with this shift. In this category, we found studies that offered K-12 teachers a variety of PD opportunities in STEM and engineering education.

Gordy et al. (2021), for example, described how high school science teachers shifted their instructional design during the pandemic, focusing on the kind of technologically integrated instructional strategies they utilized. The participants were chosen from a PD program called Science Teaching Excites Medical Interest (STEMI). Teachers were taught how to create STEM lessons for flipped classrooms during the STEMI PD. Teachers' previous experiences with various technologies allowed them to swiftly adopt online learning environments, the participating teachers showed increased confidence in their abilities to shift to remote learning.

Chen and Cao (2022) examined how a virtual PD program affected teachers' understanding of makerspaces and maker pedagogy. The study included 43 in-service teachers who were enrolled in a graduate program. The virtual PD experience allowed teachers to interact with a variety of tools, and the authors focused on teachers' maker experiences from the perspective of TPACK. Teachers were requested to create lesson plans, but there was no discussion of how teachers supported design through the use of various technologies. In another study, Wallace et al. (2021) investigated how to provide PD for STEM instructors during museum closures. Pedagogy was also explored in this study, with a focus on science education. Wallace et al. emphasized the need to utilize a variety of technologies, as well as promoting student discussions and gaining access to data sets. However, the emphasis was not on engineering design.

Another important issue raised by instructors was the difficulty of adapting their STEM or engineering curriculum in the event of a pandemic. To help teachers, Aykan and Yildirim (2022) provided PD opportunities and used a lesson study approach to help science educators. The authors investigated how teachers approach STEM and how they incorporate these concepts into lesson plans created remotely.

Benitz and Yang (2021) conducted a three-year experiment with elementary school students, instructors, and undergraduate students in order to develop a cross-disciplinary relationship between engineering and education. Researchers examined undergraduate students' progress and self-efficacy for designing and implementing engineering design in the classroom over the course of a semester for the study. Several lessons were prepared by the cross-disciplinary team, which included undergraduate students from engineering and education disciplines, and incorporated engineering design. Before starting to implement these lessons in fourth-grade classrooms, the researchers provided PD to teachers to familiarize them with the core ideas and practices presented in the Next Generation Science Standards and to help them gain confidence in teaching engineering and science to fourth-grade students. The final year of the study was primarily conducted remotely due to the COVID-19 pandemic. Fourth-graders were required to follow some lectures online and complete engineering design tasks at home as a result. Undergraduate students supported teachers and participated in remote implementations. When the authors compared the pre- and post-performance (self-efficacy, result expectancy) of undergraduate students, the authors reported that both engineering and education students showed an increase. Engineering students improved their skill development and self-efficacy more than education students.

Larson and Farnsworth (2020) created a five-week mentor program for middle and high school teachers to help them teach online lab-based STEM. After five weeks, the researchers gave teachers synchronous and asynchronous training and asked them to construct engineering lesson plans suitable for online education. Teachers built small kits for students and utilized videos to illustrate design ideas. After creating their lesson plans, the teachers shared them with others to discuss if they followed universal design for learning principles. Padlet was used to keep track of the design process. Kier and Johnson (2022) conducted another study to determine the effects of collaboration between upper secondary teachers and undergraduate STEM mentors in teaching science, technology, and engineering during the pandemic. The researchers provided instructors and undergraduates with engineering design PD and encouraged them to use what they learned in a student engineering design challenge using the digital engineering design notebook and pedagogical frameworks. The digital engineering design notebook allowed educators to leverage Google Slides technology in an interactive way, allowing students to record their thoughts and design decisions while also encouraging collaboration between students and instructors.

Discussion and Conclusion

The complete shift to remote education during the COVID-19 pandemic is defined as an abrupt shift (Colclasure et al., 2021), but it is crucial to note that distance education research has long explored novel ways of promoting students' engagement (Beldarrain, 2006). Before the COVID-19 pandemic, engineering education used virtual studios (Erden et al., 2000; Koutsabasis & Vosinakis, 2012) or virtual labs (Balid et al., 2012; Kollöffel & de Jong, 2013; Simoff et al., 2002) to promote distance learning. During the COVID-19 pandemic, scholars continued to include new examples, such as the role of virtual design studios (Nespoli et al., 2021) and virtual labs (Hristova et al., 2021).

Our systematic review of K-12 engineering and STEM education research found trends similar to those of other studies conducted in the abrupt transition (Benitz & Yang, 2021; del Rosario et al., 2020) during the COVID-19 pandemic. The first theme in our analysis was connected to studies discussing students' (Marstaller, 2020; Naydenova & Chernev, 2020; Radu et al., 2020) and teachers' (Aldon et al., 2021; Amram & Davidovitch, 2021; Jelinska & Paradowski, 2021; Khlaif et al., 2021) adaptation to online learning and the effects of an abrupt shift during the COVID-19 pandemic.

STEM teachers stress the challenges (Code et al., 2020; Makamure & Tsakeni, 2020; Panisoara et al., 2020), but it is crucial to note that there is more that should be highlighted beyond the challenges that teachers experience. Morgan et al. (2021), for example, examined the disconnect between STEM education and policy, claiming that the pandemic disproportionately impacts people of color. One of the recent reports from the National Academies of Sciences, Engineering, and Medicine (Self, 2021) found that students' STEM achievement is related to socioeconomic class, race, and ethnicity. In another report, Rotermund and Burke (2021) added that STEM teachers with fewer years of experience are more common in schools with a significant minority or low-income population. While multiple papers continue to highlight discrepancies in STEM education, there is a need for more research of inequities in K-12 engineering and STEM education during the pandemic.

During the pandemic, Self (2021) presented case studies from the United States to demonstrate how teachers worked to support scientific and engineering practices. Our review of K-12 engineering and STEM education studies included case studies from various scholars in various nations. However, due to the small number of studies, we were unable to report a transition or trajectory between them. Through the use of tools that instructors may quickly access, K-12 engineering studies promoted blended learning, flipped learning, and maker pedagogy. For example, in K-12 engineering studies, movies were the most commonly used tool (Abouhashem et al., 2021; ElSayary, 2021; Larson & Farnsworth, 2020; Wright & Bartholomew, 2020).

Transitioning a pedagogy from traditional to online settings requires a comprehensive approach from teachers and researchers in order to provide quality strategies for enhancing the learning experience for students (Deák et al., 2021). Providing more PD opportunities would be vital in supporting this goal (Aykan & Yildirim, 2022; Gordy et al., 2021). Adopting engineering education procedures to online settings also requires using new tools to support the design process (Google Slides in Kier and Johnson, 2022; Padlet in Larson and Farnsworth, 2020). However, the scarcity of examples geared at assisting teachers in delivering engineering or engineering-related activities via online platforms (Kilty et al., 2021; Larson & Farnsworth, 2020) raises concerns regarding this transition. When teachers are given the opportunity to enhance their experience with different applications of digital technology and engineering education activities, their level of confidence may rise (Beardsley et al., 2021). In fact, teachers with prior remote education experience were more engaged and handled the transition better (Jelinska & Paradowski, 2021). Increased use of online learning tools and technologies in K-12 engineering and STEM education would assist teachers in providing new opportunities for students.

In both phases of our search, we discovered that the vast majority of the research was conducted in a higher education setting (Estrada & Prasolova-Førland, 2022; Morelock et al., 2020; Nogales-Delgado et al., 2020; Ożadowicz, 2020; Singhal et al., 2020). Various strategies for supporting engineering design in K-12 education were utilized in the small number of studies exploring K-12 engineering and STEM education during the pandemic. The majority of the studies in our review were conducted by researchers in the United States. Teachers continued their classes online under the conditions of their educational system and the opportunities that they have, so the impacts of the pandemic lockdown on education appear to differ in each country (Aldon et al. 2021). Finally, it is encouraging to see that throughout the pandemic, K-12 engineering and STEM education studies examined how to enhance student learning in STEM outreach programs (Gilchrist et al., 2021; Kilty et al., 2021) and museums (Wallace et al., 2021). The examples that we have discussed in this review simply showed how to use tools; they did not show how to establish virtual labs and design studios for teachers and students.

Limitations and Implications

When we looked at the number of studies in our systematic review, the United States came out on top. We presented examples from 15 different countries that emerged in our review. However, a lack of diversity may not imply a lack of engineering education publications in local languages in many nations. Our results only summarize articles published in English in selected databases. Furthermore, our results were restricted to the search keywords. We ran our search in two phases to overcome this obstacle, but we only focused on a limited number of keywords and databases.

We included STEM-related keywords in the second phase to reach more studies in our review. The results of our analysis reveal the strong emphasis on STEM education in K-12 engineering education. The paucity of engineering studies in K-12 education emerges as another limitation for our review. Several studies conducted during the pandemic (e.g., Baptista et al., 2020; Gilchrist et al., 2021) primarily focused on STEM education, with discussion of connections to K-12 engineering education. We hope that our results may help pre-college engineering education researchers learn from STEM education studies.

Various pandemics (the 1918 H1N1 influenza pandemic, the 1957 H2N2 influenza pandemic, and the 2009 H1N1 influenza pandemic) have affected the world throughout the last hundred years. While responses to the most recent H1N1 influenza pandemic remained local, the COVID-19 pandemic prompted "large-scale e-learning for the first time" (Mohammed, 2021, p. 217), and "the pandemic is increasing the need to master digital scenarios in educational communities" (Guiza & Bennasar, 2021, p. 89). The scarcity of examples found under various categories, on the other hand, may limit the possible characteristics discovered. For example, Ng et al. (2022) noted that student motivation in online courses is an essential topic for research. It is also worth remembering that special education students miss out on personal feedback and face-to-face interaction during online programs (Mohammed, 2021). Furthermore, Collado et al. (2021) revealed that in the Philippines during the pandemic, food safety and parental involvement were major determinants of student engagement. According to Devkota (2021), the pandemic exacerbated inequality among university students in Nepal. The range of research topics is essential for understanding how all of these diverse aspects/themes may influence K-12 engineering and STEM education.

Based on how the engineering community responded to the COVID-19 pandemic, we may conclude that K-12 engineering and STEM education were likely caught off guard during the COVID-19 pandemic. The studies during the COVID-19 pandemic mostly focused on higher education, and more research is needed to understand how distance education tools and pedagogies might be implemented into K-12 engineering and STEM education. More studies from different countries are needed in this subject to better understand how K-12 engineering and STEM education studies responded to the pandemic in different countries. The findings of this study remind us that there is still much work to be done in the field of K-12 engineering and STEM education, especially given the possibility that online learning will become a permanent part of the curriculum.

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