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Conducting Experiments in Science, Technology, Engineering, and Math (STEM) in Remote Learning Environments during the Global COVID-19 Pandemic: Approaches and Policy Implications

Abstract

When the COVID-19 pandemic forced school closures, science, technology, engineering, and mathematics (STEM) teachers were left with the challenging task of devising ways for students to conduct experiments at home. This was necessary because experiments and other hands-on activities are integral to STEM education and are linked to the development of students' critical thinking skills, academic achievement, and science-related real-world skills. Based on a literature review, this study examines the methods used at the time to conduct STEM experiments remotely and provides recommendations for educational policy and practice. Findings indicate that experiential and immersive learning were the two main strategies used to accomplish home-based STEM experiments. However, experiential learning appeared to be the most prevalent and easiest to implement, especially in disciplines such as biology and environmental science. Based on the successes and limitations of the two approaches, the study concludes that consciously incorporating experiential and immersive learning into educational policies and practises would be a significant step toward better preparing teachers and students to employ them in emergency situations when teaching and learning have to be conducted remotely.

Keywords: COVID-19, STEM, experiential learning, immersive learning, place-based learning

Introduction

As a result of the COVID-19 pandemic, there was a significant shift from traditional face-to-face classroom instruction to online or remote learning. The transition for certain subjects and courses in schools and universities was relatively easy and did not present too many problems. However, it was particularly difficult for science, technology, engineering, and mathematics (STEM) courses. Even before the COVID-19 pandemic, STEM-related fields were among the most resistant to remote learning, due in part to the need for more hands-on and practical lab instruction and a lack of experience with online STEM education (Hou et al., 2022).

Gya and Bjune (2021) provide a synthesis of research that may explain STEM's emphasis on hands-on learning and resistance to remote learning. They contend that engaging in practical activities is associated with improved academic performance, increased academic self-esteem, and increased independence in learning environments. It prepares students for their future careers by providing them with authentic science-related skills and competencies. Further, it promotes critical thinking in students,

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enabling them to pose novel questions and hypotheses, design experiments, and analyse data, thereby leading to the discovery of novel results and the advancement of scientific fields. The closure of schools and learning centres as a result of the COVID-19 pandemic separated teachers and students from labs, implying that these numerous benefits of STEM practical lessons were supposed to be lost. However, some teachers employed certain strategies to give students hands-on experience. This paper reviews these strategies and discusses their implications for education policy and practice.

Research questions

The following research questions guided the study:

- During the COVID-19 pandemic, how were STEM experiments conducted outside school-based laboratories?
- What are the policy and practice implications of the learning strategies employed during COVID-19 to conduct STEM experiments outside school-based laboratories?

Methods

The study was based on an analysis of English-language studies that looked at how STEM hands-on lessons were delivered in online and remote settings as a result of the COVID-19 lockdown. The search for literature was restricted to the Web of Science Core Collection. The query that produced the most relevant results was: ((“STEM education”) AND (“COVID-19” OR “pandemic”)). Although no publication years were specified, this query showed that the earliest articles were published in 2020. In addition, no restrictions were placed on research fields because preliminary analyses revealed that the topic was relatively new and being studied across diverse disciplines. The search was conducted on December 19, 2022.

Article selection procedure

The query yielded 103 articles, the abstracts of which were screened to determine their relevance to the study. Articles eliminated during preliminary screening were: 5 review articles, 3 duplicates, 3 on STEM boot camps, and 46 general articles (they either dealt with or mentioned STEM, online learning, distance learning, and COVID-19 in passing or concerned regular in-person teaching). A few of the remaining 46 articles appeared to be pertinent to the study’s objectives, while others dealt with teachers’ and students’ experiences with remote and distance learning in general; however, it was unclear from their abstracts to what extent they met the paper’s objectives. Therefore, all 46 articles were downloaded for further screening. Only 14 of the 46 articles were finally determined to be pertinent for the study’s goals after carefully analysing their methodologies and findings.

Analysis

The extracted articles were meticulously analysed to determine their STEM field affiliations. In addition, the broad pedagogical approaches that were used to conduct the STEM experiments described in the articles were identified. Methods sections of the papers provided the majority of the information necessary for this task. In the results section, examples of articles representing the various pedagogical approaches are provided.

Results

Nine of the articles were based on a sample of university students, while the remaining five involved primary, lower secondary, and upper secondary students. The papers were distributed according to STEM fields as follows: physics (3), biology and environmental science (5), engineering (2), chemistry (2), aviation (1), and interdisciplinary (a mix of STEM and social sciences) (1). Ten of the articles were also based on pedagogical practices implemented in regular classes, while the remaining four were experiments or tests of technological applications in remote settings. Where an article appeared to bestride two or more STEM disciplines, it was assigned to the one to which the majority of the article is devoted.

In terms of pedagogical approaches, two major categories were found, which are conveniently described in this paper as experiential learning (nine articles) and immersive learning or experiments in virtual environments (five articles). The experiential learning group included all of the biology-environment articles, two of the engineering articles, and two of the physics articles. The remaining five articles fell under the immersive learning category. Nearly all of the articles made it abundantly clear that their preferred pedagogical approaches were necessitated by the inability to conduct in-person STEM experiments due to COVID-19 restrictions.

Experiential learning and its implementation

Nine of the pedagogical practices identified in the reviewed studies fall within one or more of the five experiential teaching approaches proposed by Wurdinger and Bezon (2009). They suggest place-based learning, project-based learning, active learning, problem-based learning, and service learning. All of the articles under this learning approach utilised at least the generic concept "experiential" or one or more concepts that are synonyms with experiential learning or some of its various types. Only Arroyo et al. (2022) purposefully and explicitly labelled their study as service-based learning, whereas Songer and Ibarrola's (2021) approach involved the same service-based learning but is not explicitly described as such in their article.

The most prevalent of the five aforementioned types of experiential learning was place-based education. Sobel (2004, p. 5) defines place-based education as "using the local community and environment" to teach concepts in multiple curricular areas, with an emphasis on "hands-on, real-world learning experiences" that improve students' achievements and social skills while fostering a deeper appreciation for the environment. Gya and Bjune (2021) are an example from the reviewed articles. They assigned experiments on bryophytes' water-holding capacity and seed germination in a plant biology course. Students were instructed to use household items in the experiment. Students collected, dried, and weighed bryophytes using kitchen scales to determine their water retention capacities. Some students used tomato and apple seeds from home for the seed germination experiment. The authors plan to repeat the experiment in their regular classes due to its success.

Service-based learning was the next common approach. According to Kaye (2004), service learning is an educational approach based on research that incorporates community service into either guided or classroom learning. The study by Arroyo et al. (2022) is an example. To teach fourth-year civil engineering students about seismic vulnerability assessment, they utilised a remote service-based learning approach. The assignment required students to conduct a seismic vulnerability assessment of their own homes. By allowing students to complete this assignment at home, they discovered they had a vested interest in doing so, not only to fulfil course requirements but also to evaluate their living space, identify its strengths, weaknesses, and structural flaws, and communicate this information to their families and neighbours (Arroyo et al., 2022).

The benefits and limitations of experiential learning

According to the reviewed studies, experiential learning is associated with greater levels of student dedication to learning and achievement (Arroyo et al., 2022; Songer & Ibarrola, 2021). Additionally, it is associated with increased levels of autonomy in both teachers and students (Baptista et al., 2020). Moreover, experiential learning is essential for fostering positive and robust school-community engagement. It provides one of the few opportunities for families to become acquainted with their children's educational pursuits; the practical activities students perform at home also serve as impressions to the children and their families of what their future careers might entail (Arroyo et al., 2022). The biology and environment-related studies also often concluded that experiential learning activities increase students' interest in conservation and environmental protection.

Some of the studies found that students who engage in experiential learning struggle with time management. This is especially true for students who had entire semesters to complete their experiments and observations but choose to procrastinate. According to a number of studies, students become frustrated when they are required to use skills they lack, such as video recording and editing, to complete experiential learning tasks (Schulze et al., 2021). Moreover, there are issues with the management of quantitative data, which a number of studies have identified as a challenge. In Baptista et al. (2020) as in the majority of studies, lower secondary students who had to measure neighbourhood noise levels as part of a do-it-yourself physics assignment were required to enter data using Excel, which was difficult for them; the inability to receive immediate assistance from teachers exacerbated students' frustrations. Some of the studies report similar instances of teacher frustration at having to supervise experiential learning projects or use unfamiliar technologies for the first time. According to Baptista et al. (2020), teachers also felt unprepared to adapt and transition to experiential learning.

Immersive learning: STEM experiments in virtual laboratories

Immersive learning is learning in technologically mediated environments that create a sense of presence in learners (Kuhail et al., 2022). Virtual reality (VR) is one type of immersive technology that was utilised during the COVID-19 pandemic to enhance students' practical STEM experiences. VR environments provide students with "synthetic sensory information that leads to perceptions of environments and their contents as if they were authentic" (Blascovich et al., 2002, p. 105). Augmented reality (AR) is another immersive technology that combines virtual content with real images to illustrate concepts and principles in the real world in order to enhance learners' interaction with the real world (Kuhail et al., 2022). For each of the five studies on immersive learning, researchers either created new applications or systems from scratch or enhanced existing ones in order to achieve the immersive learning goals. An example of an AR article is illustrated below.

Rodríguez et al. (2021) created interactive augmented reality (AR) web-based applications that ran smoothly on smart phones, tablets, and laptops with webcams so teachers and students could study organic, inorganic, and biological chemistry at home. Users could print and focus their webcams on 2D AR markers available on the website (such as atomic orbitals, hydrogen bonding, and molecular shapes). Once completed according to the instructions, users were able to visualise the models on their screens and interactively manipulate and investigate their structures and interactions.

Benefits and limitations of immersive learning

From the five studies, it is evident that AR and VR are indispensable for conducting STEM practical lessons remotely. For instance, according to Rodriguez et al. (2021), in-class and online surveys indicate that users find their platform engaging and useful for chemistry instruction and study. Qorbani et al. (2021) demonstrate that AVR environments permit students to practise chemistry lab procedures, make mistakes, and correct them, thereby decreasing the risk of accidents and poor performance in actual labs. Nevertheless, because AR and VR are based on technological mediums, it is not always possible to deploy them on a large scale, which limits their accessibility. For example, Rodriguez et al. (2021) discovered that more than half of the teachers and students who utilised their website to study chemistry had no prior experience with AR technologies.

Discussion and policy implications

Experiential and immersive learning are not new concepts in the field of education. Researchers have connected the works of early 20th-century authors such as John Dewey, Kurt Lewin, and Jean Piaget to the notion of experiential education (Miettinen, 2000). In addition, learning in virtual environments was proposed for the first time in the 1990s, but its theoretical models are significantly older (Blascovich et al., 2002).

It is unclear, however, how frequently these strategies are employed in schools and whether they are the result of intentional policy design. Regardless of how they are implemented in schools, this study argues that standard STEM curricula should intentionally incorporate experiential and immersive learning due to their demonstrated effectiveness and difficulties of implementation. This would better prepare teachers and students to employ them during crisis and as low-cost alternatives to doing experiments. Also, their intentional inclusion is important because when educational practises are one-time events, they are not as beneficial to educational systems as when they are part of ongoing intentional design practises (Cobb & Jackson, 2012). Additionally, their inclusion would help teachers recognise that their practises are part of larger learning frameworks with implementation principles. This would put teachers in a better position to not only evaluate whether students performed well in STEM do-it-yourself projects, but also to reflect on how their practises align with some stated instructional principles.

Regularly integrating experiential and immersive learning into teachers' activities may also afford both teachers and students opportunities to develop a sense of autonomy in the learning process. For teachers, autonomy is implicit in delegating duties—instructing students to conduct certain experiments outside of school—and for students, autonomy is implicit in undertaking such activities at their own pace and independently directing and monitoring progress. Increased autonomy is enormously important. For teachers, for example, this would increase job satisfaction and "perceptions of workload manageability and intention to stay in the profession" (Worth & Van den Brande, 2020, p. 3).

The following actions may be required in order to set policy objectives for experiential and immersive learning. Firstly, they need to be incorporated into teacher training programs. This would help avoid the situation where teachers feel unprepared to implement such teaching strategies as reported in Baptista et al. (2020). Secondly, STEM curricula and syllabuses should include mandatory at-home experiment activities for students. Furthermore, because immersive learning, in particular, necessitates technological mediums, increased funding for low-cost technologies is required.

This study recognises that not all STEM courses and topics can be taught using any of the identified methods, as their utility is likely to decrease as the complexity of the intended experiments increases. Consequently, the study contends that in times of crisis, educators should not be concerned with implementing STEM activities in a pre-determined order, but rather should look for simple and inexpensive activities within existing lesson plans and syllabuses and implement them using the appropriate approaches. This suggests skipping activities and returning to them when things return to normal, which, it should be stressed, is only appropriate for activities that do not build on one another.

Conclusions

The study was based on a literature review on the implementation of hands-on STEM lessons in remote learning contexts following the COVID-19 outbreak. Two approaches to remote STEM experiments were observed: experiential and immersive learning. It appears that experiential learning is the simplest to implement, particularly in fields such as biology and environmental science, though both approaches have implementation challenges. Specifically, the expansion of immersive learning would necessitate an increase in funding for the development of easily accessible virtual learning technologies. We discovered a scarcity of literature on this topic, which could be attributed to the fact that our search was limited to the Web of Science Core Collection. Therefore, we recommend that future research include additional citation databases to determine how thoroughly the topic has been studied.

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References

Arroyo, O., Barreto-Tovar, C. H. & Feliciano, D. (2022): Service Learning as a Teaching Strategy of Seismic Vulnerability during the COVID-19 Pandemic. *International Journal of Engineering Education*, 38(5), 1484-1494.

Baptista, M., Costa, E. & Martins, I. (2020): STEM Education during the COVID-19: Teachers' Perspectives about Strategies, Challenges and Effects on Students' Learning. *Journal of Baltic Science Education*, 19(n6A), 1043-1054.

Blascovich, J., Loomis, J., Beall, A. C., Swinth, K. R., Hoyt, C. L. & Bailenson, J. N. (2002): Immersive virtual environment technology as a methodological tool for social psychology. *Psychological inquiry*, 13(2), 103-124.

Cobb, P. & Jackson, K. (2012): Analyzing educational policies: A learning design perspective. *Journal of the Learning Sciences*, 21(4), 487-521.

Gya, R. & Bjune, A. E. (2021): Taking practical learning in STEM education home: Examples from do-it-yourself experiments in plant biology. *Ecology and evolution*, 11(8), 3481-3487.

Hou, Y., Ghasemkhani, A., Aldirawi, H., McIntyre, M. & Van Wart, M. (2022): Shifts in STEM Student Perceptions of Online Classes across 18 Months. *American Journal of Distance Education*, 1-20. https://doi.org/10.1080/08923647.2022.2121521 (Accessed 19.11.2022).

Kaye, C. B. (2004): *The Complete Guide to Service Learning: Proven, Practical Ways to Engage Students in Civic Responsibility, Academic Curriculum & Social Action*. Minneapolis: Free Spirit Publishing.

Kuhail, M. A., ElSayary, A., Farooq, S. & Alghamdi, A. (2022): Exploring Immersive Learning Experiences: A Survey. *Informatics*, 9(4), 1-32.

Miettinen, R. (2000): The concept of experiential learning and John Dewey's theory of reflective thought and action. *International journal of lifelong education*, 19(1), 54-72.

Qorbani, H. S., Arya, A., Nowlan, N. & Abdinejad, M. (2021): Simulation and Assessment of Safety Procedure in an Immersive Virtual Reality (IVR) Laboratory. *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (pp. 589-590). Lisbon, Portugal.

Rodríguez, F. C., Frattini, G., Krapp, L. F., Martinez-Hung, H., Moreno, D. M., Roldán, M., ... & Abriata, L. A. (2021): MoleculARweb: A web site for chemistry and structural biology education through interactive augmented reality out of the box in commodity devices. *Journal of Chemical Education*, 98(7), 2243-2255.

Schulze, A., Hajduk, M. M., Hannon, M. C. & Hubbard, E. A. (2021): Invertebrate film festival: Science, creativity, and flexibility in a virtual teaching environment. *Invertebrate Biology*, 140(1), 1-10.

Sobel, D. (2004): Place-based education: Connecting classroom and community. *Nature and listening*, 4(1), 1-7.

Songer, N. B. & Ibarrola Recalde, G. D. (2021): Eco-solutioning: The design and evaluation of a curricular unit to foster students' creation of solutions to address local socio-scientific issues. *Frontiers in Education*, 6(March), 1-10.

Worth, J. & Van den Brande, J. (2020): *Teacher Autonomy: How Does It Relate to Job Satisfaction and Retention?* Slough, Berkshire: National Foundation for Educational Research.

Wurdinger, S. D. & Bezon, J. L. (2009): Teaching practices that promote student learning: Five experiential approaches. *Journal of Teaching and Learning*, 6(1), 1-13.

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