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EDITORIAL

How Can Emerging Technologies Impact STEM Education?

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Abstract

In this editorial, we discuss the affordances and challenges of emerging technologies in designing and implementing STEM education as a planned theme of this special issue. We view that emerging technologies, such as artificial intelligence (AI) and virtual reality, have a double-edged sword effect on STEM learning and teaching. Exploring the effect will help provide a balanced view that simultaneously recognizes the benefits and pitfalls of the technologies and avoids overstating either one. This themed issue highlights how immersive and AI-driven learning environments advance and transform STEM education in different contexts. It consists of this editorial, three research reviews, and two empirical research articles contributed by scholars from five different regions, including Australia, Hong Kong, mainland China, Singapore, and the USA. They discussed the educational, social, and technological effects of emerging technologies. Each article discusses to various extent about the current research status, what and how the technologies can afford, and what concerns the technologies may bring to STEM education.

Keywords Artificial intelligence (AI) · Computational thinking · Emerging technologies · STEM education · Virtual reality (VR)

Introduction

Emerging technologies can drive changes throughout the educational landscape, leading to redefinition and reshaping of STEM (science, technology, engineering, and mathematics) education. Connecting with and developing skills in technologies is invaluable for being part of the rapidly evolving STEM learning and teaching environments. STEM education should utilize the capabilities and possibilities

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of technologies to create innovative learning experiences, which enhances students' learning with new tools and environments such as artificial intelligence (AI), biotechnology, robots, virtual reality (VR), intelligent tutoring systems, STEM digital tools, and the next generation of learning management system. Students will need to develop new knowledge and skills to use appropriate emerging technologies to solve contemporary STEM real-world problems. These emerging technologies bring great opportunities for transforming the forms and ways of interactions and collaborations among individuals and with environments. At the same time, those changes can also be viewed as having the potentially disruptive power to interrupt our usual practices and policies and either to ameliorate or exacerbate social and historical inequities. Many questions remain in virtually every aspect of the learning and teaching process with the use of that technologies, such as students' engagement, learning process, learning interest, outcomes, and instructional design. These questions call for extensive research needed to examine the untapped potential of these technologies in ways that can advance STEM education successfully. This collection of five articles addressed some of these questions from eastern and western perspectives through research reviews and empirical studies with a focus on AI and immersive technologies such as VR.

Overview of the Five Articles

These five articles cover a broad range of issues related to the educational, social, and technological effects of AI and immersive technologies on STEM education.

The first three articles used a systematics review approach to explore the educational, pedagogical, and technological effects of emerging technologies on STEM education. The first article, written by Chng et al. (2023), demonstrates how AI and immersive technologies advance STEM education by identifying and reviewing 82 journal papers. The authors analyzed the papers from two perspectives—doing things better and doing better things. Their findings discovered that VR and natural language processing were two popular technologies utilized in STEM education, that their use intended to nurture science epistemic skills, and that AI was used to forecast students' future STEM careers. However, they argued that it is not evident how these technologies may contribute to the advancement of STEM education due to their pedagogical affordances and constraints.

The second article is an analysis of 17 empirical studies by Ouyang et al. (2023). The purpose of this review was to examine the use of AI in STEM educational assessment from three areas—academic performance assessment, learning status assessment, and instructional quality assessment. The findings showed that deep learning was employed in most of the AI application's algorithm and that AI was mostly used for evaluating students' academic performance. They suggested that AI can assist students acquire the capacity to think across disciplines and provide them the tools they need to solve real-world problems by integrating their STEM knowledge and skills. Due to the rising development of AI-based applications for educational assessment, their findings also showed that digital literacy is a requirement for students' and teachers' AI usage.

The third article is a descriptive review by Zhang et al. (2023) on computational thinking in Science, Technology, Engineering, Arts, and Mathematics (STEAM) early childhood education context. They identified and selected nine journal papers for an in-depth investigation. The results indicated that young children had positive learning experiences in a coding-as-playground environment (Bers et al., 2019), that they should acquire reasoning, creative, and algorithmic thinking (Angeli & Valanides, 2020; Bers et al., 2019), and that there were no gender differences in computational thinking utilizing educational robotics (Angeli & Valanides, 2020).

The last two articles in this issue addressed the design and implementation and evaluation of STEM learning and teaching with the emerging technologies across various educational levels—PreK-12 and higher education—as well as concerns over the use of the technologies. Specifically, the fourth article is an Australian qualitative study by Izadinia (2023). The author examined 23 Sydney high school students to determine how VR may be used to create an engaging learning environment that boosts girls' confidence, engagement, and interest in STEAM. The results revealed that while studying STEAM using VR, girls felt more comfortable and secured utilizing the immersive digital technology. The apparent increase in self-efficacy and confidence motivated girls to pursue jobs in the field of technology by increasing their engagement and interest.

The last article, written by Majewska and Vereen (2023), investigated how undergraduate students and their instructors in the USA regard the use of VR for biology learning. Examining the impact of VR on the biology learning of undergraduates, they used a questionnaire and a test and instructors' lecture notes to gain a deeper understanding of the advantages and difficulties that immersive technology brings to science learning. Their findings suggested that students perceived a positive attitude toward STEM and immersive technologies when learning with VR. Instructors developed a positive attitude toward VR because they were able to interact with their students in more authentic ways. They were concerned, however, that the technologies might exacerbate the digital divide between rural and urban areas.

In sum, the key themes that emerged from the aforementioned studies concern the affordances and challenges in the absence of adequately designed and robust pedagogies, along with the need of developing instructors' and students' skills and repertoires. These themes demonstrate that emerging technologies are two-edged swords. It is a great chance to advance STEM education, but we are not prepared for it. Students and teachers may find technology easy to use, but they will always expect more from technologies. Technologies are evolving faster than ever before; therefore, it is important to explore and understand the opportunities and challenges they present for transforming STEM education.

Building upon these five articles, we perceive three key opportunities and three key challenges that are relevant in an AI- and metaverse-driven STEM education and beyond. In the next two sections, we discuss how emerging technologies can advance STEM instruction (three key opportunities), followed by presenting three challenges of using the technologies in STEM education. In the last section, we make recommendations for future research direction in the hopes that they will stimulate further discussions among researchers and practitioners about the roles of emerging technologies and their impact on STEM education research and practices.

In What Ways, and to What Extent, May Emerging Technologies Advance STEM Instruction?

Providing a More Inclusive, Diverse, and Equitable Education to Improve STEM Workforce Development

STEM educators prioritize inclusivity, diversity, and equity to ensure a comprehensive and impactful education that benefits all students (El-Hamamsy et al., 2023). The inequalities in STEM education have negative effects on the inclusivity and diversity of STEM careers, implying that students' future employment prospects may be harmed by a lack of an appropriate STEM instructional design. Since there is a growing need for STEM professionals, not just the involved students but the workforce and economy as a whole may be negatively impacted by the inequity in STEM education. The inequity may be viewed in two ways—gender and digital (Sevilla et al., 2023). Due to gender bias and stereotypes, girls are underrepresented in STEM education and jobs. Gender stereotypes and a lack of female role models are two important factors that discourage young girls from pursuing STEM fields (Freedman et al., 2023; Herrmann, et al., 2016; Piatek-Jimenez et al., 2018). The second point of view is digital inequity or divide. This is due to accessibility and digital skills (Resta & Laferrière, 2015). Students who lack digital skills or reside in remote regions are less likely to obtain a more comprehensive STEM education because they lack access to the technologies and resources needed to participate in STEM activities.

The special issue takes a new perspective at how VR and coding may encourage more female and non-STEM students to participate in STEM activities. With the advancement of user-friendly interface, many emerging technologies do not necessitate the perceived need of acquiring specialized skills. They are designed for everyone. Students found VR beneficial and simple to use, establishing a more positive attitude toward technology and STEM learning (Izadinia, 2023; Majewska & Vereen, 2023; Zhang et al., 2023). This is explained by Davis' (1989) technology acceptance model, which is a major paradigm for understanding the adoption of new technologies in a variety of contexts. According to the model, technology self-efficacy, perceived ease of use, usefulness to use, and attitude toward can predict behavioral intention to, intrinsic motivation to, and actual usage of a technology. This implies that students (boys and girls, computer enthusiasts and non-enthusiasts) are more motivated to use VR and coding in STEM learning (Yu et al., 2021). This intrinsic motivation is also strongly associated with STEM interest and identity development that can predict career choice (Chiu, 2023; Izadinia, 2023; Majewska & Vereen, 2023). Emerging technologies empower and engage girls and computer non-enthusiasts in STEM education, increasing their likelihood of developing a stronger interest and identity toward STEM (Izadinia, 2023; Majewska & Vereen, 2023; Zhang et al., 2023). Furthermore, Ouyang et al.'s (2023) study revealed that AI analytics can predict student STEM career involvement and that AI-based virtual mentors may help students grow their STEM careers. To summarize, incorporating emerging technologies into STEM education reduces the likelihood of students

falling behind in a way that permanently eliminates them from STEM-related fields. It has the potential to open up the future STEM job opportunities and boost the workforce development by offering a more equitable education.

Encouraging Other Fields to Be Included for Greater Transdisciplinary STEM Learning

Interdisciplinary STEM education is an approach by which students learn the interconnectedness of the disciplines of STEM. Students analyze real-world problems by gathering ideas from STEM disciplines and then integrating these ideas for conducting a more comprehensive analysis. This education needs to be carried out through well-designed curriculum and innovative pedagogy. The interdisciplinary level is affected by teachers' perceptions and pedagogical content knowledge and students' discipline knowledge in STEM (Margot & Kettler, 2019; Thibaut et al., 2018). For example, teachers who have a positive attitude toward STEM and students who have greater abilities are more likely to integrate STEM disciplines in problem-solving. Teacher education is essential to the promotion of interdisciplinary STEM education (Thibaut et al., 2018).

Instead of taking a focus on teacher education, in this special issue, we advocate for the use of emerging technologies to create a learning environment conducive to interdisciplinary learning. For example, Izadinia (2023) claimed that VR can involve students in digital arts for STEM learning; Ouyang et al. (2023) revealed that students may readily utilize AI to solve problems in integrated ways. These findings could be explained by the theory of experiential learning (Fromm et al., 2021) and interdisciplinary nature of AI (Casal-Otero et al., 2023). VR can enable experiential learning, allowing students to learn via participant experience or by doing. Students will be able to explore problems and utilize multiple discipline knowledge to complete tasks in an authentic scenario in VR settings. AI is viewed as an interdisciplinary field that includes computer science, mathematics, physics, neurology, psychology, and languages. Understanding how AI works requires interdisciplinary approaches (Chiu et al., 2022). AI learning assistants also can help student to gain interdisciplinary STEM knowledge (Carlos et al., 2023). These also imply that emerging technologies—VR and AI—have advantages to include other disciplines in STEM education. For example, both Izadinia (2023) and Zhang et al. (2023) found that VR and coding can help students explore digital art and expand STEM to STEAM. AI goes beyond STEM and often includes knowledge from other disciplines such as history and geography. Integrating AI in STEM would make STEM more interdisciplinary and readily include other disciplines (Park et al., 2023). Therefore, using emerging technologies could create a learning environment that fosters more interdisciplinary STEM education.

Rethinking the Major Learning Outcomes

Emerging technologies, especially AI and the metaverse, have an impact on our society. Some of the jobs will be replaced by technologies, while others have not yet to be created. Skills for the future workforce have evolved. To better equip the next generation, we need to refocus our education efforts and nurture student skills, such as computational thinking, AI literacy, creativity, leaderships, and collaborative skills. These are evidenced in various global educational initiatives like STEM education and AI education for K-12 (Casal-Otero et al., 2023; Chiu et al., 2022), as well as design thinking and global leadership programs (Kijima et al., 2021; Li et al., 2019a). Our education needs to adapt to the shifting nature of working environment in the future.

The major learning outcomes of interdisciplinary STEM education include STEM knowledge, twenty-first century competencies, interdisciplinary thinking, and STEM interest and identity (Anderson & Li, 2020; Li et al., 2019b). This special issue suggests that, due to the impact of emerging technologies, we should rethink the learning outcomes of STEM education. The "T" and "E" in STEM education are directly influenced by emerging technologies, for instance, students would design and create their own solutions to solve a real-world problem. The "S" and "M" are the foundational knowledge of emerging technologies; for instance, computer vision algorithms are derived from sets of mathematical equations. The findings of the five articles in this issue show that algorithmic and computational thinking, as well as digital, AI, and media literacy, should be core learning outcomes of future STEM education. To strengthen the future workforce, STEM educators and researchers should thus incorporate the learning outcomes in their educational or research projects.

What Challenges and Issues May Emerging Technologies Pose to STEM Instruction, and What New Skills Will Students and Teachers Be Required?

Widening Digital Divide

Emerging technologies are double-edged swords and have the potential to both lessen and exacerbate the digital divide. As previously noted, emerging technologies designed for educational purposes are accessible to a wide range of students and user-friendly (Izadinia, 2023; Majewska & Vereen, 2023; Ouyang et al., 2023; Zhang et al., 2023), hence reducing the digital gap in STEM education. To build more sophisticated solutions, students need to have a firm grasp of mathematics and hard sciences, in addition to strong technical skills in developing technologies (Majewska & Vereen, 2023). As emerging educational technologies become more accessible to young kids, the technologies to be utilized by young kids depend on the school's resources and the digital competency of the teachers, including their technical knowledge and skills, as well as attitude and value. Most schools and

teachers are resistant to change (Chng et al., 2023); nevertheless, incorporating new technologies into STEM education represents a significant change for both schools and teachers. Consequently, emerging technologies may worsen the digital divide if schools and teachers do not receive adequate resources and professional training and support, respectively.

Enhancing Prerequisite Skills Needed for Emerging Technology-Enhanced STEM Education

Emerging technologies come with the benefit of fostering new learning skills, but they also call for the development of new prerequisite skills in order to make more successful use of the technologies in STEM education. Despite the fact that the educational technologies are simple to use, a strong foundation of necessary prior knowledge is required for more effective and safe learning and teaching. Articles in this special issue suggest that the required skills include computational thinking, digital literacy, and AI literacy (Chng et al., 2023; Ouyang et al., 2023; Zhang et al., 2023). We believe that it shall be beneficial for students if these skills are taught to them in elementary or middle school. Consideration ought to be given by educational institutions to the development of basic curricula for learning and teaching these skills.

Encountering Technical and Health Concerns

Emerging technologies in STEM education may cause technical and health concerns in implementation. It is time-consuming for teachers to experiment with emerging technologies or design-related materials prior to STEM classes (Majewska & Vereen, 2023). Less-well-prepared teachers are more likely to experience technical issues in STEM lessons with emerging technologies. When technological issues arise, it is difficult or impossible to deliver an emerging technology-driven STEM lesson. In addition, some technologies, such as VR, may pose health risks (Izadinia, 2023; Majewska & Vereen, 2023). Teacher's knowledge of the technologies will help lessen the incidence of these technical and health concerns. Providing relevant professional training and support is necessary for using emerging technologies in STEM education.

Concluding Thoughts and Future Research Directions

With the inclusion of a limited number of articles, this special issue indicates the initial stage of research in this topic area. There are still many research areas regarding the use of emerging technologies in STEM education that are exciting but remain to be explored. For example, a line of possible research work is the provision of safe learning environments when employing emerging technologies in STEM education. For the purpose of optimizing learning, emerging technologies such as AI and avatars in the metaverse may capture students' personal information such as learning

data, body movement, and face and voice data. How the technologies collected and used the data can associate with privacy and ethical concerns. Another issue is the psychological safety of students. Some students may become addicted to VR and AI and find it difficult to leave the virtual and chatbot environments. Their emotions, such as fear or anger, may be elicited by the environments, influencing their decision-making. Even in the digital environments, maintaining psychological safety is still very much relevant and important to promote STEM learning. Therefore, we suggest that future research should focus on how to create safe learning environments while incorporating emerging technologies in STEM education, taking into consideration of those ethical, privacy, and psychological concerns.

Teacher professional learning is another area that is underserved. Even though four of the five articles addressed teacher involvement in STEM education, none of them examined what and how to provide professional learning for the use of emerging technologies in STEM education. To successfully employ emerging technologies, teachers must have sufficient pedagogical knowledge and skills as well as digital literacy (Chng et al., 2023; Ouyang et al., 2023). Policy on ethical, privacy, and psychological considerations necessitates the engagement of educational leaders. We encourage future research should focus on how to design, develop, and deliver professional learning for both teachers and leaders.

Concerning theoretical perspectives, Ouyang et al. (2023) brought up the last line of work. Theoretical support is missing from most studies that use emerging technologies in STEM education. According to those studies, emerging technologies for STEM education were developed and used in new ways. They discussed how teachers and students can use technologies to teach and learn STEM subjects. Most of those studies did not utilize a theoretical framework to examine and interpret their findings. Therefore, future studies should look at their designs and findings from certain theoretical point of view of learning and development.

We hope that the publication of this special issue will inspire researchers to further explore and broaden the field's knowledge of how emerging technologies transform STEM education, as well as how theories may be developed and used to explain and support the key role of the technologies in STEM learning and teaching. Finally, we encourage researchers and educators to consider possible benefits and difficulties that emerging technologies can offer to STEM education and to envision what a bright future STEM education can be.

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Declarations

Competing Interests The authors declare no competing interests.

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