Development of STEM and STREAM education Post Covid-19: A comparative review and challenges for future research

Pembangunan pendidikan STEM dan STREAM Pasca Covid-19: Kajian perbandingan dan cabaran untuk penyelidikan masa hadapan

Titiyaka Jajuri[1,2], Nor Asniza Ishak[1*], Shahabuddin Hashim[1], Mohd Yahya Fadzli Jusoh[1]

[1]Pusat Pengajian Ilmu Pendidikan, Universiti Sains Malaysia, Pulau Pinang, Malaysia
[2]Kolej Matrikulasi Perak, Gopeng, Malaysia

*Corresponding author: asnizaishak@usm.my

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ABSTRACT

The COVID-19 pandemic has significantly impacted education systems worldwide, including the fields of Science, Technology, Engineering, and Mathematics (STEM) and Science, Technology, Robotics, Engineering, Arts, and Mathematics (STREAM). A future-oriented education on critical issues, such as those outlined in the United Nations Sustainable Development Goals (UN SDGs), and designing potential solutions for such problems is an imperative skill that must be imparted to students to help them navigate their future in today's unpredictable world. As schools transitioned to remote learning, educators faced numerous challenges in delivering effective STEM and STREAM education.

This research provides a comparative focus on the post-pandemic development of STEM and STREAM education. Through binary qualitative relationship methods and ideographic nomothetic methods, quantitative comparisons, qualitative comparisons, changes, adaptations, and challenges faced by educators and students are identified. Furthermore, the paper identifies key areas for future research to address the evolving needs and opportunities in STEM and STREAM education. Both STEM and STREAM education foster critical thinking, problem-solving, creativity, collaboration, and communication skills, providing students with a practical and hands-on approach to learning. By following the engineering design process, students engage in real-world problem-solving and develop the mindset and skills necessary for success in STEM fields and beyond.

Keywords: STEM and STREAM education, remote learning, sustainability in education

ABSTRAK

Pandemik Covid-19 telah memberi kesan ketara kepada sistem pendidikan di seluruh dunia, termasuk bidang STEM (Sains, Teknologi, Kejuruteraan dan Matematik) dan STREAM (Sains, Teknologi, Robotik, Kejuruteraan, Seni dan Matematik). Pendidikan berorientasikan masa hadapan mengenai isu-isu kritikal, seperti yang digariskan dalam Matlamat Pembangunan Lestari Pertubuhan Bangsa-Bangsa Bersatu (UN SDGs) dan mereka bentuk penyelesaian yang berpotensi untuk masalah tersebut merupakan kemahiran penting yang harus disediakan kepada pelajar untuk membantu mereka menavigasi masa hadapan mereka dalam masa yang sukar diramalkan hari ini. Institusi pendididikan kini beralih kepada pembelajaran jarak jauh, maka pendidik menghadapi pelbagai cabaran dalam melaksanakan pendidikan STEM dan STREAM yang berkesan.
Penyelidikan ini memberi fokus perbandingan perkembangan pasca-pandemik bagi pendidikan STEM dan STREAM. Melalui kaedah perhubungan kualitatif binari dan kaedah nomotetik ideografi, perbandingan kuantitatif, kualitatif, perubahan, penyesuaian dan cabaran yang dihadapi oleh pendidik dan pelajar dapat dikenalpasti. Justeru itu, penyelidikan ini dapat mengenal pasti bidang utama untuk penyelidikan masa hadapan dalam menangani keperluan dan peluang yang berkembang dalam pendidikan STEM dan STREAM. Selain daripada itu, pendidikan STEM dan STREAM memupuk pemikiran kritis, penyelesaian masalah, kreativiti, kerjasama dan kemahiran komunikasi dan memberikan pelajar pendekatan praktikal untuk pembelajaran. Melalui proses reka bentuk kejuruteraan, pelajar terlibat dalam penyelesaian masalah dunia sebenar dan membangunkan minda serta kemahiran yang diperlukan untuk berjaya dalam bidang STEM pada masa hadapan.

***Kata kunci**: Pendidikan STEM dan STREAM, pembelajaran jarak jauh, kemampanan pendidikan*

INTRODUCTION

The presence of the National Science Foundation (NSF) created the STEM educational project, formerly known as Science, Mathematics, Engineering, and Technology (Sanders, 2009), to develop students' capacity for critical thought and problem-solving, which helps students compete better in good practices in STEM careers. STEM education, according to Colucci-Gray et al. (2017), Christou et al. (2022), and Shruti Mahajan (2022), is a multidisciplinary approach to learning and is perceived to be crucial in bolstering the professional abilities required for future economic development and careers.

In line with the aim for future economic development and careers, The American Arts-National Policy Roundtable in 2007 brought the limitations of STEM to light. As a result, it was decided that the Sciences, Technology, Engineering, Arts, and Mathematics (STEAM) approach would be a more sustainable way to foster involvement and competency among the new generation in STEM (Allina, 2018). Based on professional STEAM disciplines, Land (2013) claimed that promoting the next generation to research various answers to challenging problems is essential. Therefore, including the arts in STEM can help with this problem and allow for the development and stimulation of creativity in STEM students. However, how do disciplines or subjects such as STEAM look through the lenses of sustainability justice? The concept of sustainability justice is applied widely in the four pillars of sustainable development: environment, society, economy, and culture (Makrakis, 2018). Furthermore, causal factors leading to STREAM education that infuse sustainability justice demonstrate a link between constructs of knowledge, empathy, compassion, social solidarity, and action competencies (Makrakis, 2017).

According to the study by NEA (2012), early intervention of the Science, Technology, Robotics, Engineering, Arts, and Mathematics (STREAM) approach introducing the "Three Rs" (Reading, Writing, and Arithmetic) is no longer sufficient to satisfy the developmental needs of STEM learners in response to the rapid changes within the context of Industrial Revolution 4.0 (IR4.0) and also from a justice perspective (Jing Ling et al., 2023). Notably, the STREAM-based curriculum that infuses sustainability justice can overcome this gap since it can facilitate students to develop 21st-century abilities. At the same time, "collaboration, communication, creativity, and critical thinking" make their integration and meaningfulness possible (Thao Nguyen et al., 2021). Interestingly, STREAM has been gaining popularity in many countries for the following reasons: (1) Enhances 21st-century skills; (2) Releases creativity; (3) Enables learning and practice; and (4) Promotes student-centered learning (Nguyen et al., 2021) with the point of social justice provides engaging, empowering, and authentic contexts (Bond & Chernoff, 2015).

Unfortunately, in light of the post-COVID-19 era, student recruitment and retention have become even more crucial in ensuring that the significance of generating a positive learning environment remains sustainable in developing students' performance in STEM (Bazilah et al., 2024) and STREAM education. Moreover, the development of STEM and STREAM education was severely impacted by the pandemic. Accordingly, educational institutions had to shift toward the essential goal of student satisfaction in learning STEM and STREAM education rates to remain high (Alangari, 2022). The lessons learned by institutions and student experiences of remote delivery during the pandemic will shape students' future expectations of learning, teaching, and assessments, emphasize the need for institutions to focus on their unique selling points of developing STEM and STREAM education in a competitive market (Chen & Chen, 2021). Thus, this adaptation in the educational system posits a challenging question: which mode of learning would best develop STEM and STREAM education in the post-COVID-19 era? Therefore, drawing on the comparative review of post-COVID-19 STEM and STREAM education, this study explores the differential impact of changes and innovations in STEM and STREAM education and challenges for future research to perform in STEM and STREAM line education.

Background STEM AND STREAM Education

Recent developments in STEM and STREAM education have led to a renewed interest in shifts in instructional delivery methods that can nurture the exchange of critical insights and ideas to tap into a sustainable learning environment after COVID-19 (Loretta et al., 2021). Notably, these two fields each have unique characteristics, and deciding which one is better for students to pursue can be challenging. We first examine STEM education, which involves an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply STEM in a context that connects school, community, work, and the global enterprise. This enables the development of STEM literacy and, with it, the ability to compete in the new economy (Zulirfan et al., 2020). In particular, professionals who are well-versed in the STEM fields and their many subfields (Statistics, Biology, Psychology, Economics, Agriculture, and Aeronautics) largely drive high demand worldwide as these two systems interact. In addition, jobs in STEM fields have increased by more than 79% since 1990, such as the cognitive field at 31.8%, psychiatric field at 28.4%, sensory/communicative field at 21.5%, physical fields at 18.2% faster than the broader US job market, according to the Pew Research Center (2019).

Considerable design limitations of STEM: STREAM education is an approach to preparing a quality STEM workforce and literate citizens for a highly technology-based society by integrating science, technology, engineering, arts, reading, writing, and mathematics in education (Nguyen et al., 2021). It is named differently from STEM due to its emphasis on arts (fine arts, language arts, liberal arts, and physical arts), with additional sustainability education as a critical component of integration (Avraam et al., 2022). Furthermore, with the idea of creating innovative thinkers by integrating ideas from STREAM fields, i.e., all subjects in institutions, the term 'convergence education' has been coined and used to refer to the integrated STREAM education initiative (Razi et al., 2022). Meanwhile, convergence refers to creating new ideas or products formed by interdisciplinary (MacDonald, 2019) or multidisciplinary (Michailidis, 2020) thinking. Thus, the main goal of integrated STREAM education is to develop 'talents in convergence' (Miller, 2021). In light of these shifts and the increasing value placed on soft skills across industries and vocations, it is becoming clear that courses of study that combine STEM and other disciplines are necessary (Mohd Razali et.al., 2022).

According to the review above, workers in STEM fields who also possess artistic abilities and a broad grasp of the humanities are better able to come up with novel solutions to challenges. Humanities, language arts, dance, theatre, music, visual arts, design, new media, and more are all a part of STREAM-focused curricula (Antionadis, 2019). Thus, students who pursue and master any of these areas can make themselves more employable in today's workforce, increasing their proficiency in the "soft skills" that contribute to becoming an effective worker or a hands-on position in engineering.

This section has attempted to briefly summarize the interrelationship between STEM and STREAM education in terms of providing students with a well-rounded education rather than teaching each subject separately. Both of these perspectives help us comprehend the world and the work field. When trying to solve a problem, most studies consider as many aspects of it as possible and formulate an overall strategy based on the fact that STEM and STREAM are interchangeable in this regard. In the real world, students need diverse abilities to succeed in their professional and personal endeavors. When all these abilities are combined, the result is a highly competent person.

RESEARCH PROBLEMS

Exposure to COVID-19 outbreaks in 2020 has been proven to be related to adverse effects on the instructional delivery methods of STEM and STREAM education. As the pandemic spread, most classrooms abruptly shifted to an online format. Emergency Remote Teaching (ERT) describes the "temporary shift of instructional delivery to an alternate delivery mode due to crisis circumstances" (Hodges et al., 2020). In typical circumstances, distance learning can take advantage of the affordances of online tools that can promote student-centered, experiential learning (Hodges et al., 2020). For instance, students can learn STEM or STREAM online collaboratively (e.g., by recording data on shared Google Sheets) or self-paced with personalized lessons (i.e., video-based STEM or STREAM lessons). Furthermore, STEM and STREAM education have embraced various digital tools and platforms to facilitate virtual labs, simulations, coding activities, and collaborative projects. Accordingly, this allows students to continue their hands-on learning experiences from the comfort of their own homes.

Turning now, the acceleration of shifts in instructional delivery methods of STEM and STREAM education must consider the effects of COVID-19. The responses relating to the effects of ERT, the instructional delivery methods of STEM, and STREAM education after the COVID-19 crisis strike about blended education system or hybrid (Singh et al., 2021). A blended education system comprising both face-to-face and media classes, including online classes (Singh et al., 2021; Singh & Matthees, 2021). Therefore, in the future, it will be necessary to combine these various types of classes effectively according to the specific class circumstances (e.g., target students, number of participants, personnel such as teachers, and teaching assistants). Therefore, most institutions decided to rebuild and mold face-to-face interactive classes to suit the online format. This rapid change from face-to-face to online classes reduced students' interactive participation and needed to create opportunities for them to understand and react to the contents. In online teaching, including interactive elements like short quizzes is recommended (Gewin, 2020). In addition, the previous studies conducted during a face-to-face class discovered that students had a self-identified need for examples and games that aided intuitive understanding (Jason et al., 2018; Claudiu Coman et al., 2020; Hatabu et al., 2021).

RESEARCH OBJECTIVE

A comparative study is a method that analyzes phenomena and then puts them together to investigate the points of differentiation and similarity (Mokhtarian Pour, 2016). Specifically, new insights emerging during the course of this research process yield reconsiderations and revisions of preliminary decisions. The objectives of the study:

1. Presents a comparative review of the post-pandemic development of STEM and STREAM education by:

   i) binary qualitative relations,
   ii) nomothetic and ideographic methods of quantitative comparison.

2. Identifies key areas for future research to address the evolving needs and opportunities in STEM and STREAM education from the nomothetic and ideographic analysis.

RESEARCH METHOD

Research design

For this study, a qualitative comparative analysis was the main method for highlighting the similarities and differences between the units in this study, STEM and STREAM education (Bolbakov et al., 2020). To present comparative findings, many ways have been drawn to pay attention to and support comparative analysis, such as tables, figures, or narrative descriptions. The conclusion and implications section summarizes the key findings, discusses relevance to the research objectives, explores implications for literature review or practice, and suggests directions for future research. This methodology helps ensure that the results of this comparative study are effectively communicated and contribute meaningfully to the field of study in STEM and STREAM education (Cavallo B. et al., 2019).

Measurement scales, both nominal and ordinal, are used for qualitative comparison. It uses qualitative binary relations like better, equal, less, and more. The comparison, in this instance, is predicated on identifying a binary relationship between the items being compared or their attributes (Cavallo et al., 2019). Through comparison, a qualitative feature is produced. In this case, the simple comparison is based on a pairwise comparison of STEM and STREAM education. Weighing scales are the most basic comparing tool. It seems that the comparison parameter STEM and STREAM is weight, and the comparison criterion is equality or inequality. We use a comparison operator:

$$Compare\ (A(x), B(x), C). \qquad (1)$$

In expression (1) Compare – comparison operator, $A(x)$ – the first comparison parameter, x – comparison parameter, $B(x)$ – the second comparison object, C – comparison criterion. Kudzh and Tsvetkov (2020) stated that x is the weight, C is the equality of the weighing scales. In these circumstances, on the nominal scale, the operator's action is described by a logical expression.

Table 1: Comparison operator for qualitative binary relations

Comparison operator	Comparison criterion
$If\ (A(x) = B(x))$	$then\ 1,\ else\ 0$
$If\ (A(x) \neq B(x))$	$then\ 0,\ else\ 1$

Source: *Bolbakov et al. (2020). Methods of comparative analysis, pg 2*

However, the multi-parameter comparison uses nomothetic and ideographic approaches (Hermans, 1988). The goal of nomothetic thought and cognition is to identify recurring themes, relationships, and rules. An ideological approach to cognition and thinking looks for distinctive characteristics and facts (Castro & Ferrer, 2013). Thus, it is recommended that the Trinitarian model of the compared objects (Figure 1) be utilized to compare these strategies. This model highlights the parameters of the comparable items. Meanwhile, the object's uniqueness is demonstrated by encircling the unique parameters.

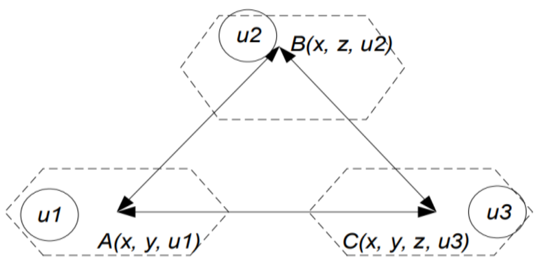

Figure 1: Trinitarian model of items under comparison

The formulation of the comparison problem using the example of three related objects is summarized in Figure 1. The Trinitarian comparative analysis goes as follows. There are objects $A(x, y, u1)$, $B(x, z, u2)$, $C(x, y, z, u3)$ which contain common parameters (x, y, z) and unique parameters $(u1, u2, u3)$ (features).

FINDINGS

A. Utilization Of Technology and Digital Resources

The COVID-19 pandemic has brought about significant changes in various aspects of our lives, including a noticeable increase in the utilization of technology and digital resources for STEM and STREAM education (Yang & Baldwin, 2020). This trend can be attributed to factors such as enhanced learning opportunities, real-world connections, personalized learning, collaboration and communication, and career readiness.

The first observed increase in enhanced learning opportunities could be attributed to technology providing students with access to a wide range of digital resources, such as interactive simulations, virtual laboratories, and online research databases (Dias et al., 2020; Raza et al., 2021). These resources offer hands-on experiences and opportunities for exploration that may not be feasible in traditional classroom settings. Accordingly, students can engage in virtual experiments (Worner et al., 2022), manipulate data, and collaborate with peers, enhancing their understanding of STEM and STREAM concepts. Consequently, real-world connections appear possible as technology allows students to connect their learning to real-world applications (Shin et al., 2022). Through digital tools, students can explore how STEM or STREAM principles are applied in various industries and professions. In addition, they can engage in virtual field trips, interact with experts through video conferencing, and access online platforms that showcase real-world examples of STEM or STREAM in action. This helps students see the relevance and practicality of STEM and STREAM education.

On the other hand, technology enables personalized learning experiences tailored to individual student needs (Zheng et al., 2022). In particular, adaptive learning platforms and educational apps can provide targeted instruction, adaptive assessments, and immediate feedback. This allows students to progress at their own pace, reinforcing their understanding of STEM or STREAM concepts and addressing knowledge gaps. In contrast, according to Johler (2022), due to collaboration and communication factors, digital resources facilitate collaboration and communication among students, both locally and globally. Furthermore, online platforms and tools enable students to collaborate on projects, share ideas, and provide feedback. This collaborative approach fosters teamwork, problem-solving skills, and cross-cultural understanding, preparing students for future careers in STEM or STREAM fields. Moreover, Guilbaud and Jennings (2021) highlighted that utilizing technology and digital resources in STEM and STREAM education aligns with the demands of the modern workforce. Hence, by familiarizing students with digital tools and technologies, they develop the skills necessary for future careers in STEM-related fields. This includes proficiency in data analysis, programming, digital design, and critical thinking, which are highly valued in today's job market and reflect their career readiness.

Overall, the increased utilization of technology and digital resources in STEM and STREAM education provides students with enriched learning experiences, real-world connections, personalized learning opportunities, and collaboration and prepares them for future careers in STEM and STREAM fields.

B. Challenges in Remote Learning Environments

Remote learning environments face common challenges in both STEM and STREAM education, primarily due to the lack of face-to-face communication and the absence of non-verbal cues. This lack of interaction can make establishing personal connections and engaging in spontaneous discussions difficult, as noted by Anderson and Singh (2021) and Dhawan (2020). Moreover, technological limitations, such as poor internet connectivity, can disrupt communication and hinder interaction, emphasizing the heavy reliance on technology in remote learning (Powell, 2020; Riniker, 2021; Yıldırım, 2021).

Collaborative activities, essential for interactive learning, are more challenging to facilitate remotely. Notably, group discussions, brainstorming sessions, and hands-on projects suffer from the lack of immediate and direct interaction, impacting the quality of collaborative learning experiences (Leisi Pei & Hongbin Wu, 2019; Huang et al., 2020). The sense of isolation and reduced social interaction can diminish the sense of community among students (Loretta et al., 2021). However, innovative approaches, such as using Instagram to promote engagement (Rohini, 2021) and online portfolios as alternative assessments (Chavis, 2021), demonstrate efforts to keep students engaged in remote settings.

In STEM education, online platforms and simulations can replicate hands-on experiences, and teachers can use video demonstrations and real-time monitoring to ensure safety and engagement (Ivan V. & Andrea V., 2017). In STREAM education, digital artwork and virtual galleries facilitate artistic expression, enabling students to collaborate and receive feedback through video conferencing and discussion forums (Black, Ferdig & Thompson, 2021). While these strategies help address some challenges, adapting instructional approaches is crucial to maintaining the quality of education in remote settings.

C. Blended Learning Models and Hybrid Approaches

Blended learning enhances STEM and STREAM education by allowing students to explore concepts through interactive experiments, simulations, and online resources. This hands-on approach helps students better understand and retain content (Basilaia, 2020). Additionally, blended learning offers flexibility, enabling students to access resources and complete assignments at their own pace, catering to different learning styles and abilities.

Furthermore, in STEM education, blended learning promotes interdisciplinary learning through project-based activities. For instance, students might design a sustainable energy system by applying knowledge from STEM. In addition, using computer simulations and online tools, they can observe the connections between various STEM subjects, enhancing their understanding and application of concepts (Abichandani et al., 2022).

Moreover, blended learning provides access to virtual labs, interactive simulations, and coding platforms, engaging students in hands-on STEM activities. These resources help students apply knowledge, solve problems, and think critically. Additionally, online platforms facilitate collaboration and teamwork, mirroring real-world STEM environments where professionals work together on complex problems (Byrnes et al., 2021).

In STREAM education, blended learning incorporates robotics and arts into traditional STEM subjects. Students might design and build robots, applying STEAM principles. This interdisciplinary approach fosters creativity, innovation, and critical thinking (Dewi et al., 2021). Additionally, online resources and tools, such as 3D modeling software and coding platforms, support these activities, allowing students to engage dynamically with STREAM concepts.

In summary, blended learning models and hybrid approaches in STEM education integrate various disciplines (Science, Technology, Engineering, and Mathematics) to provide students with a holistic understanding of their interconnectedness. Thus, by incorporating online resources, facilitating interdisciplinary learning, and promoting collaboration, these approaches prepare students for the multidisciplinary nature of STEM fields. The findings of this paper provide insights into blended learning models and hybrid approaches in STREAM education, integrating various disciplines to provide students with a comprehensive and interdisciplinary education. Hence, incorporating online resources, supporting creativity and critical thinking, and promoting collaboration prepare students for the diverse and evolving demands of the modern workforce.

D. Teacher Professional Development and Training Programs

As an implication of changes and innovation in STEM as long as STREAM education emerged after the COVID-19 pandemic, various professional development and training programs were raised for STEM and STREAM education teachers. These programs provide educators with the necessary skills, knowledge, and strategies to effectively integrate STEM and STREAM concepts into their teaching practices, in-person or virtual (DeCoito & Estaiteyeh, 2022). Furthermore, different professional development and training programs are highlighted as relevant to both STEM and STREAM education practitioners.

A substantial number of organizations and institutions offer online courses and webinars specifically designed for STEM and STREAM education (Chung et al., 2021). These programs cover topics such as inquiry-based learning, project-based learning, integrating technology, coding and robotics, assessment strategies, and curriculum development. Furthermore, online courses and webinars reveal teachers with the flexibility to learn at their own pace and engage in interactive discussions with experts and fellow educators. For example, Zheng et al. (2021) researched virtual workshops and conferences that provided opportunities for teachers to explore professional development and networking in STEM and STREAM education. Online courses and webinars concentrate on how feature keynote speakers, panel discussions, interactive sessions, and hands-on activities are involved. Moreover, educators can engage with innovative teaching methods, best practices, and emerging technologies in STEM and STREAM education. Virtual workshops and conferences also allow for collaboration and knowledge-sharing among educators from various locations.

Online communities and professional networks reported by Rad et al. (2021) focused on STEM and STREAM education enable educators to connect with fellow educators, share resources, and exchange ideas. These platforms were another advantage for collaboration, discussion, and support of others. Educators and students can participate in online forums, join virtual interest groups, and access a wealth of resources and lesson plans shared by their peers. The wide range of mentoring and coaching programs pair experienced STEM and STREAM educators with teachers who are new to these instructional approaches. In addition, mentors can provide guidance, support, and feedback to help teachers implement effective STEM and STREAM practices in their classrooms (Grineski et al., 2022). These mentoring and coaching programs can be conducted through virtual platforms, allowing regular communication and collaboration between mentors and mentees.

It is possible that these factors will make curriculum development and resource training for all educators reproducible due to the latest demanding nature of the learning environment. To strengthen the aspect of curriculum development and resource training, teachers can participate in training programs that focus on curriculum development and the effective use of resources for STEM and STREAM education. Thus, a more comprehensive program can guide aligning curriculum with standards, selecting appropriate resources, and adapting lessons for different learning environments, including integrating hands-on activities, technology tools, and real-world connections into their lessons (Fung et al., 2021). More than that, collaborative lesson planning and sharing initiatives (Zollinger & DiCindio, 2021) allow educators to work together to develop and refine STEM and STREAM lessons. Teachers can collaborate virtually to design engaging activities, share lesson plans, and provide feedback on each other’s work. This collaborative approach fosters creativity, innovation, and continuous improvement in STEM and STREAM instruction (Boice et al., 2021). Therefore, it is vital for educators to explore available opportunities, stay updated with current research and best practices in STEM and STREAM education, and continuously enhance their skills to provide high-quality STEM and STREAM learning experiences for their students.

DISCUSSION OF FINDINGS

In response to the challenges posed by the pandemic, both STEM and STREAM education have recognized the significance of flexibility and personalization. Educators tailor instruction to meet individual students' needs and adjust their approaches based on the unique circumstances faced by each student. Overall, Collaboration and Learning Environment (CLE) the shift to remote learning has presented challenges; however, it has also sparked innovative approaches to instructional delivery. STEM and STREAM education have adapted by leveraging technology, embracing project-based learning, fostering creativity, and prioritizing personalized learning experiences.

A comparative review of post-COVID-19 STEM and STREAM education from three perspectives, such as shifts in instructional delivery methods, challenges in remote learning environments, and utilization of technology and digital resources, can help educators adopt effective strategies to support and guide student learning in facing post-COVID environments. It is critical to note that the strategies described in the selected studies supported students' learning and enhanced students' "experiences in meaningful ways," as summarized in Table 2 below:

Table 2. Comparative review of post-COVID-19 STEM and STREAM education

	STEM	STREAM
Shifts in instructional delivery methods	**Similarity**	
	• Emergency Remote Teaching (ERT) • Hybrid or Blended Learning • Collaboration and Learning Environment (CLE)	
	Differences	
	• Inquiry-based learning • student-centered teaching • problem-solving skills	**PICRAT:** • **PIC:** classifies students as passive, interactive, creative • **RAT:** teachers as replacement, amplification, transformation
Challenges in remote learning environments	**Common Challenges:**	
	• Limited Hands-On Activities and Reduced Interaction • Access to Resources	
	Additional Challenges	
	• Lab Safety and Supervision • Technical Challenges	• Artistic Expression • Collaborative Artwork
	Similarity	

continued

Utilization of technology and digital resources	• Have witnessed an increased utilization of technology and digital resources.	
	Differences	
	• Virtual Labs and Simulations • Data Analysis and Visualization • Coding and Programming	• Digital Design Tools • Multimedia Creation • Virtual Performances and Exhibitions

By infusing blended learning models and hybrid approaches with educators' professional development and training programs, we can expose the adaptations and innovations in STEM and STREAM education in authentic contexts and provide opportunities to develop technical skills that highlight the learning of STEM and STREAM disciplines. It is evidently provided in Table 3.

Table 3. The Adaptations and innovations in STEM and STREAM education

	STEM	STREAM
Blended learning models and hybrid approaches	**Similarity**	
	Students receive a well-rounded education where they can explore concepts through interactive experiments, simulations, and online resources.	
	Differences	
	Integrates various disciplines: Science, Technology, Engineering, and Mathematics.	Integrates various disciplines: Science, Technology, Robotics, Engineering, Arts, and Mathematics.
Teacher professional development and training programs	**Similarity**	
	Aims to equip educators with the necessary skills, knowledge, and strategies to effectively integrate STEM and STREAM concepts into their teaching practices, whether in-person or in virtual settings.	
	Differences	
	Project Lead the Way (PLTW): National Science Foundation (NSF) Teacher Institutes NASA Educator Professional Development	Employs cutting-edge instructional techniques, discovers new technologies and tools, and gains insights into integrating arts and design into STEM subjects.

The scope of this research was relatively narrow, being primarily concerned with comparison parameters between STEM and STREAM education, with either equality or inequality as the criterion. When the scales come to equilibrium, it is assumed that the weighted sum of standards is equal to the weight of the object under study (Bolbakov et al., 2020). Table 4's fascinating analysis provides valuable insight into binary qualitative relations about the comparative review of post-COVID-19 STEM and STREAM education from three perspectives, as well as the adaptations and innovations in STEM and STREAM education.

Table 4. Binary Qualitative relations between STEM and STREAM education post-COVID

Comparison Parameter	Comparison operator	Comparison criterion
Shifts in instructional delivery methods	$If\ (\text{STEM}(x) \neq \text{STREAM}(x))$	$then\ 0, else\ 1$
Challenges in remote learning environments	$If\ (\text{STEM}(x) = \text{STREAM}(x))$	$then\ 1, else\ 0$
Utilization of technology and digital resources	$If\ (\text{STEM}(x) = \text{STREAM}(x))$	$then\ 1, else\ 0$
Blended learning models and hybrid approaches	$If\ (\text{STEM}(x) = \text{STREAM}(x))$	$then\ 1, else\ 0$
Teacher professional development and training programs	$If\ (\text{STEM}(x) \neq \text{STREAM}(x))$	$then\ 0, else\ 1$

From the table, it is a significant mark that binary qualitative relations between STEM and STREAM education post-COVID criterion are equal with the synthesis 3/5. The comparative review and challenges outlined in this research contribute to understanding the changes and adaptations in STEM and STREAM education post-COVID-19 in equilibrium and are specific to each field.

Another concern is that this research fails to identify key areas for future research to address the evolving needs and opportunities in STEM and STREAM education from the nomothetic and ideographic analysis (Hermans, 1988). A nomothetic method is a method of cognition aimed at establishing common (similar, related) phenomena, which is considered a way of thinking, and cognition is aimed at finding common patterns, dependencies, and laws. In contrast, ideographic thinking and cognition is looking for unique facts and properties (Castro & Ferrer, 2013). Figure 2 displays the model highlights parameters of the compared STEM and STREAM education, and the uniqueness of objects is demonstrated by placing the unique parameters in circles.

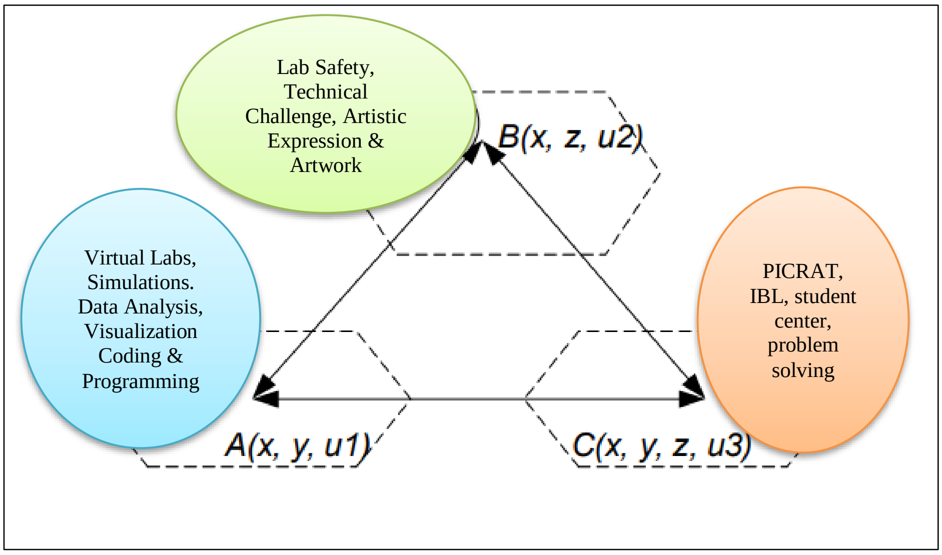

Figure 2: Trinitarian model of items under comparison between STEM and STREAM education

Figure 2 summarizes the formulation of the comparison problem using the example of three related perspectives: shifts in instructional delivery methods, challenges in remote learning environments, and utilization of technology and digital resources. The Trinitarian comparative analysis goes as follows. $A(x, y, u1)$ refers to the utilization of technology and digital resources, and $B(x, z, u2)$ refers to challenges in remote learning environments. Meanwhile, $C(x, y, z, u3)$ refers to instructional delivery methods which contain common parameters (x, y, z) and unique parameters ($u1$, $u2$, $u3$), which includes $u1$ (Virtual Labs and Simulations, Data Analysis and Visualization and Coding and Programming for STEM while Digital Design Tools, Multimedia Creation, Virtual Performances, and Exhibitions for STREAM education), $u2$ (Lab Safety, Technical Challenge, Artistic Expression & Artwork) and $u3$ (Inquiry-based learning, student-centered teaching, problem-solving skills for STEM.

x(student-centered learning) refers to the common challenges between *A*, *B*, and *C*.
y(incorporate increased use of technology in education) refers to the combination of factors *A* and *C*.
z(adaptation to new learning formats) refers to the combination of factors *B* and *C*.

IMPLICATIONS OF THE STUDY

The implications of this study are significant for the evolving landscape of STEM and STREAM education post-COVID-19. The findings, highlighted by a synthesis score of 3/5 based on binary qualitative relations, indicate that while there are areas of convergence between STEM and STREAM, particularly in challenges and the utilization of technology, key differences remain in instructional delivery methods and professional development. Furthermore, this equilibrium suggests that while both fields share common challenges and opportunities, tailored approaches are necessary to address each other's unique needs. In addition, the study underscores the significance of developing flexible, adaptable educational strategies that can accommodate both the similarities and differences between STEM and STREAM education, ensuring that both fields can thrive in a post-pandemic world.

This led to identifying key areas for future research to address the evolving needs and opportunities in STEM and STREAM education from the nomothetic and ideographic analysis. From the Trinitarian model of items under comparison between STEM and STREAM education, student-centered learning represents the main nomothetic as a "common parameter." It demonstrates unifying elements across the utilization of technology, challenges in remote learning, and instructional delivery methods in STEM and STREAM education. It also emphasizes active, personalized learning where students take charge of their educational experience, facilitated by digital tools and creative resources. However, remote learning challenges like limited interaction and resource access can hinder this approach, necessitating thoughtful integration of technology and innovative teaching methods to maintain effective, student-centered engagement.

Among the common parameters, there are universal and pairwise common parameters. Both the similarities between the utilization of technology and digital resources and shifts in instructional delivery methods clearly refer to the adaptation of increased use of technology to support learning in STEM and STREAM education. Specifically, both have adopted strategies like ERT and hybrid or blended learning to facilitate continued education, leveraging digital tools and resources to create collaborative learning environments and maintain instructional continuity. In addition, this integration highlights how technology has become a central component in both teaching methods and learning resources post-COVID-19.

Hence, the analysis focuses on the challenges of remote learning, shifts in instructional delivery methods, the similarities in adapting to new learning formats, and the limitations faced. These points illustrate how the changes in teaching methods (like adopting hybrid models and online collaboration tools) are directly linked to the challenges of limited hands-on activities, access to resources, and reduced interaction in remote learning environments.

Ideographic analysis indicates that Lab Safety, Technical Challenges, Artistic Expression, and Artwork are the unique parameters for challenges in remote learning environments. Meanwhile, Digital Design Tools, Multimedia Creation, Virtual Performances and Exhibitions for STREAM education, Virtual Labs and Simulations, Data Analysis and Visualization, and Coding and Programming are unique parameters for the usage of technology and digital resources. Furthermore, inquiry-based learning, student-centered teaching, and problem-solving abilities for STEM are some of the next distinctive characteristics of instructional delivery methods that stand out. PIC, or passive, interactive, and creative students, RAT, or teachers as a replacement, amplification, and transformation for STREAM education are other factors. It is proven that the particular difficulties faced by remote learning environments include artistic expression, artwork, technical difficulties, and lab safety. Therefore, it emphasizes the role of passive, interactive, and creative students as well as the use of digital design tools, multimedia creation, virtual labs, data analysis, and coding in STEM teaching.

CONCLUSION

Comparative analysis makes it possible to link newly acquired knowledge to worldviews. The synthesis of similarities and differences between these fields reveals that while both STEM and STREAM emphasize the central role of student-centered learning across the utilization of technology, challenges in remote learning, and shifts in instructional delivery methods, adopted increased technology use, which particularly through ERT and hybrid or blended learning. They also face distinct challenges that require tailored approaches. Nevertheless, the convergence in technology utilization and instructional shifts underscores the need for flexible, adaptable strategies that address both common challenges and the unique demands of each field, ensuring effective and personalized learning experiences in a post-pandemic world.

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