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An international perspective on STEM education: private school teachers' conceptualization – a descriptive survey study

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ABSTRACT
This study explores private school teachers' interpretations of STEM and their awareness of its distinctive features, considering regional differences. The research is descriptive, aiming to outline the general definition and characteristics of STEM education. Of 533 survey respondents, 249 teachers who were familiar with STEM and taught STEM-related subjects in different regions of the world were included. The data were collected through an online survey consisting of two sections: an open-ended question regarding the definition of STEM, and a question asking participants to select from a list of characteristics that are distinctive and non-distinctive of STEM. The results underscore the need for targeted STEM education programmes and teacher training that fit regional and local contexts while upholding global core values. The crucial point of this research is that the geographical variety and private-school teachers' differing perspectives shape conceptualisations of STEM education's nature and characteristics.

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Introduction

STEM (Science, Technology, Engineering and Mathematics) education has become more prevalent in the last decade (Fuller et al., 2021; Holmlund et al., 2018; Li et al., 2020). However, there is a conspicuous deficiency of epistemological underpinnings for how educators perceive STEM education in academic endeavours that attempt to define the boundaries of STEM education. The literature needs to provide a consensus on the definition and practices of STEM education (Bybee, 2013; McLoughlin et al., 2020; Li et al., 2022; Ring et al., 2017; Roehrig et al., 2012). Martín-Páez et al. (2019) emphasise the importance of incorporating real-world contexts into STEM learning. Ritz and Fan (2015) state that educational systems still struggle to effectively implement STEM education to solve real-world problems. Ryu et al. (2019) draw attention to the lack of STEM education practices

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because teachers may not receive or be exposed to integrated STEM education in their previous educational experiences. In this context, investigating how teachers conceptualize STEM education is crucial for supporting more meaningful and integrated STEM practices. Stohlmann et al. (2012) stress that more research is needed on the knowledge, training and experience that teachers need to implement STEM education effectively.

It is significant to understand how teachers in private schools conceptualize and implement the STEM education approach within their unique dynamics. Even within academia, diverse definitions and explanations exist regarding its conceptualization and interpretation (Akarsu et al., 2020). However, there are few comprehensive studies on how educators from different parts of the world with various demographic characteristics conceptualize STEM education and which characteristics they associate with it. Moreover, although real-world challenges, 21st century skills, and STEM occupations' promotion are recognized as essential components of integrated STEM education, teachers' conceptualizations of these elements remain unclear (Dare et al., 2021). Breiner et al. (2012) highlight that the diversity of responses to the inquiry regarding the definition of STEM education is contingent upon the source or academic milieu to which the individual endeavouring to elucidate the matter refers. Hence, exploring how educators across diverse regions worldwide, characterized by a wide range of demographic features, can offer a comprehensive spectrum of perspectives on how STEM education is conceptualized under various circumstances.

The hallmark of integrated STEM education is a holistic approach that spans several dimensions, creating a vibrant and all-encompassing learning environment Its fundamental tenet is this approach's multidisciplinary character, which smoothly integrates STEM fields. It uses a problem-based learning paradigm, in which learning opportunities are based on actual issues that represent real-world issues and call for innovative and diverse solutions (Anazifa & Djukri, 2017). Additionally, there is a focus on situations with alternative solutions, which motivates learners to investigate other viewpoints and develop creative problem-solving techniques depending on the engineering design process in primary and secondary education (Adiguzel Ulutas et al., 2023).

Regarding integration, STEM education exhibits flexibility, with some research allowing for use within a single field, while others require involvement from at least two STEM disciplines (Dugger, 2010; Ozkan & Topsakal, 2020). Additionally, a process-oriented methodology that incorporates the engineering design process and supports iterative design is a defining characteristic of integrated STEM. This methodology helps learners develop in multiple ways, allowing them to learn through practical experience and facilitating a profound grasp of real-life challenges (Guzey et al., 2016; Hurley et al., 2024; Moore et al., 2014).

The approach is fundamentally skills-based and aims to equip learners with a wide range of abilities necessary for success in the 21st century that meet societal and global expectations (Nazifah & Wang, 2022). Soft skills, seen as an essential foundation of STEM education, are also related to 21st century skills, with a strong emphasis on teaching students to learn from their mistakes and to strengthen their ethical values. The active encouragement of group collaboration fosters collaborative learning opportunities that resemble natural workplace settings. Integrated STEM education, with its emphasis on issues with a variety of solutions, instils an innovative approach, critical thinking skills, and adaptability to the complexity of today's environment (Vasquez et al., 2013). Essentially, the goal is to create learning settings where learners may develop critical evaluation skills and apply evidence-based decision-making techniques (Prastika et al., 2022). One of the most salient characteristics of the STEM education approach is its alignment with the engineering design process, facilitating problem-solving through structured, sequential, and iterative stages (Massachusetts DOE, 2006). This approach allows learners to advance through the solution iteratively, enhancing their understanding of the process and concepts involved and fostering the development of their skills (Hynes et al., 2011; Moore et al., 2014).

Nevertheless, a few naive beliefs continue to exist. A common misunderstanding about STEM is that it can only be predominated by one subject field (Akarsu et al., 2020). However, STEM is interdisciplinary, so it can easily incorporate many disciplines to produce a more comprehensive learning environment. Therefore, this understanding contradicts the nature of STEM education (Erduran, 2020). The notion that laboratory activities predominate in STEM education is the foundation of yet another myth. Practical experiences are essential; at the same time, the STEM education approach emphasizes problem-solving, critical thinking, and real-world applications in a context (Elmas, 2020). It includes a wide range of activities, including laboratory work. Contrary to the myth that it takes a teacher-centred approach, STEM education is learner-centred and frequently involves student directed research, group projects, and teamwork. With the instructor guiding the learning process, this student-centred process encourages active participation and thorough thinking. (Sulaeman et al., 2022). It is a common misconception that STEM is a largely product-oriented field that only considers the final product. STEM education prioritizes process-oriented learning outcomes, encouraging experimentation, iterative design, and problem-based learning to increase understanding (Craig, 2022). The emergence of a tangible product can undoubtedly facilitate the learning process. However, fundamental gains can also be achieved by developing ideas, models and project files (Capobianco et al., 2018; National Research Council [NRC], 2012). In addition, successful STEM initiatives depend on careful planning and the efficient use of available resources, even when certain areas require additional investment. Some studies provide STEM integration with simple materials or recyclable items. According to Ozkan et al. (2024), learners ought to be given the chance to work through open-ended challenges on their own and to develop understanding via trial-and-error processes. Furthermore, including real-world situations with an emphasis on sustainability and economic value can improve the applicability and impact of STEM education.

Finally, it is a limited perspective to associate STEM only with robotics-related activities. Robotics is one aspect of STEM education that can be useful, but a well-rounded educational experience involves a variety of disciplines, technologies and approaches. According to Barrett et al. (2014), the research indicates that many STEM programs have concentrated on disciplines, resulting in a need for more development of best practices for interdisciplinary STEM education. An increasing body of research suggests that more connected and interdisciplinary approaches to learning and improving one's skills are needed in STEM education to deal with issues (Han et al., 2020). The interdisciplinary nature of STEM education aligns with the case of many technical fields collaborating to provide practical solutions to pressing global challenges (Hubbard, 2021).

The idea of integrated STEM education highlights the necessity for a thorough grasp of STEM disciplines while acknowledging the importance of technology as a body of knowledge, skills and practices (Kelley & Knowles, 2016). There are multiple ways to refer to STEM education, including STEM teachers, STEM schools, and STEM projects. Many individuals, institutions, and organizations successfully employ these approaches when the strategies are applied accordingly (Akarsu et al., 2020; Elmas & Adiguzel Ulutas, 2022; Moore et al., 2014; Ulger & Cepni, 2020). STEM education is conceptualized in various ways by teachers depending on the social and cultural context of their region, and different countries have a variety of educational policies for disseminating STEM education (Cogan & Schmidt, 2002; Fang et al., 2013; Hamad et al., 2022).

The following defines the STEM education approach that guided this research. (Akarsu et al., 2020) This definition was chosen because it not only introduces STEM education but also highlights its key characteristics. Addressing these features provides a more comprehensive understanding of the approach.

It is an educational approach that integrates science, technology, engineering, and mathematics disciplines for the solution of real-life problems, facilitates the understanding of real-life problems with engaging and motivating experiences, and is not only product-oriented but also process and skill-oriented.

This study aims to determine private school teachers' definitions of the STEM education approach and to examine their levels of knowledge and awareness regarding the features of a STEM education approach, considering regional variations. Although the definition and characteristics of STEM have been examined in previous studies, our research reveals private school teachers' definitions of STEM and their familiarity with its characteristics using a unique sample. In addition, our study is valuable in that it offers a comparative perspective on geographical diversity. This brings a different and new perspective to the STEM literature that has not been well represented before. The research questions are as follows:

1. What overarching themes emerge in how teachers from STEM-related disciplines in private schools globally conceptualize STEM education?
2. Which attributes of STEM education are predominantly favored by teachers from STEM-related disciplines in private schools on a global scale?

Methods

This descriptive study collected data via a questionnaire validated by experts. Based on the definitions of STEM education by Akarsu et al. (2020), the questionnaire included both relevant and irrelevant characteristics of STEM education. This study makes it feasible for participants to be widely accessible and engaged by utilising the online survey platform, promoting a thorough investigation of their viewpoints on STEM education.

Participants

The participants of the study were private school teachers with a probable international curriculum experience and teachers from different regional contexts. Zech (2014) noted that many schools offering project-based STEM education are charter or private. In addition, considering the possibility of innovative pedagogies and interdisciplinary projects being implemented more widely in private schools, it was thought that private school teachers would be suitable participants for the study in terms of providing richer data collection opportunities, but this is also a limitation to be the representativeness of their region. At the beginning, the survey included 533 teachers. Since the aim of the study was to examine teachers' conceptualizations of the STEM education approach, participants who answered “No” to the question “Have you heard of STEM education before?” were excluded from the sample. The final sample consisted of 249 teachers actively working in STEM disciplines in private schools located in different parts of the world (Europe, Africa (Fr), Africa (En), the Middle East, and Asia). The distribution of participants across five distinct regions has been categorized based on their private school locations. The European region encompasses member states of the European Union alongside Eastern European countries. The African Francophone region spans countries within the African continent and is characterized by the adoption of the French educational system and the provision of education predominantly in French.

Conversely, the African Anglophone region comprises nations within Africa that adhere to the British educational system and prioritize English as the medium of instruction. The Asia-Pacific region is confined to Asian countries proximate to the Pacific basin. The Middle East region encompasses nations in Asia and close to the African basin. These geographical differences give a contextual framework for examining participants’ answers and shed light on the various educational environments and methodologies in various geopolitical locations. Table 1 presents the demographic characteristics of the sample.

Table 1

Demographic characteristics of the participants

Variables		Teachers	
		N	%
Heard about STEM education before participating in this study	Yes	249	46.7
	No	284	53.3
Gender	Female	140	56.2
	Male	109	43.8
Region	Europe	32	12.9
	African Francophone	27	10.8
	African Anglophone	50	20.1
	Middle East	51	20.5
	Asia-Pacific	89	35.7
Total teaching experience	1-5 years	78	31.3
	6-10 years	79	31.7
	11-15 years	35	14.1
	16-20 years	25	10.0
	21 and above years	32	12.9

Table 1 indicates that out of the 533 teachers, 46.7% responded "yes" to having heard of STEM education, while 53.3% responded "no." This highlights that more than half of the participants were unfamiliar with the concept of STEM education. Participants with no prior STEM exposure were purposefully excluded from the study, as the research aimed to clarify teachers' conceptualizations of STEM education. In addition to this, the majority of the participants are female, making up 56.2% of the sample, while males represent 43.8%. This indicates a balanced gender distribution, with a slight majority of female teachers.

Asia-Pacific accounted for 35.7% of the 249 participants, demonstrating the region's significant involvement in STEM education. The Middle East demonstrated participation in STEM education, with 20.5% of the participants, closely followed by the African Anglophone region (20.1%). On the other hand, Europe made up 12.9% of the sample, and the African Francophone region made up the lowest percentage (10.8%). This analysis highlights how different regions expose disparities in educational priorities and environmental factors.

The largest group of teachers (31.7%) have 6–10 years of experience, indicating that many are actively honing their teaching techniques. Those with 1–5 years of experience come in second at 31.3%, which includes a sizable portion of more recent teachers who could contribute new viewpoints to STEM teaching. On the other hand, 10.0% of teachers have 16–20 years of experience, while 14.1% have 11–15 years. Lastly, 12.9% of participants have 21 years or more of experience.

Data Collection Tool

An online survey form was used as a data collection tool in the study. The survey consists of two sections. In the first section, participants were asked to express their views on the definition of the STEM education approach through an open-ended question. In the second section, teachers were asked to select items from a list of relevant and irrelevant characteristics of STEM education. For example, "It is a teacher-centred approach" was given as an irrelevant characteristic, while "Based on real-life problems" was given as a relevant characteristic. The survey items were developed based on a literature review, particularly the definitions and characteristics of the STEM education approach presented by Akarsu et al. (2020). The list of relevant and irrelevant characteristics was reviewed by three academics with expertise in STEM education, and the items were revised in line with their feedback. A pilot application was conducted with a small group of teachers for pre-testing, and the comprehensibility and suitability of the items for the measurement purpose were evaluated. As a result of the evaluation, the wording was revised to make the items clear and understandable.

Data Analysis

Pre-existing theories, frameworks or theoretical knowledge are typically the basis for deductive data analysis research (Kyngäs & Kaakinen, 2020). In conceptualizing the definition of STEM education, a word cloud was created by determining the frequency of responses given by the teachers. The word cloud was created using the deductive analysis approach, which focused on the concepts used to define STEM on a regional basis by examining the definition of STEM in the study by Akarsu et al. (2020) and evaluating it.

Apart from the characteristics of STEM education established by Akarsu et al. (2020), the research also includes current misconceptions. As a result, participants had to critically evaluate those characteristics that either matched or deviated from the core ideas of STEM and identify the characteristics of STEM education. Concerning STEM education, this multifaceted approach aimed to elicit a thorough understanding of participants' cognitive structures, thereby explaining regional variations in the process.

Two researchers independently coded participants' responses, identifying common themes through open coding. The researchers created a high-level category for words with similar meanings. After determining the categories, the researchers re-read the participants' responses and coded them separately. The researchers conducted a separate coding procedure, carefully classifying transcripts separately and cross-referencing the results to determine inter-coder reliability. When discrepancies emerged, experts engaged in cooperative discussions to settle disagreements and reached a consensus regarding classification and coding. The study's ethical requirements were emphasized by providing participants with adequate information about the confidentiality safeguards protecting their data. Participants gave their express assent in advance by filling out a consent form, confirming that they were aware of the purpose and methods of the research and that their participation was voluntary. All participant identities were anonymized to respect their right to privacy and confidentiality.

Results

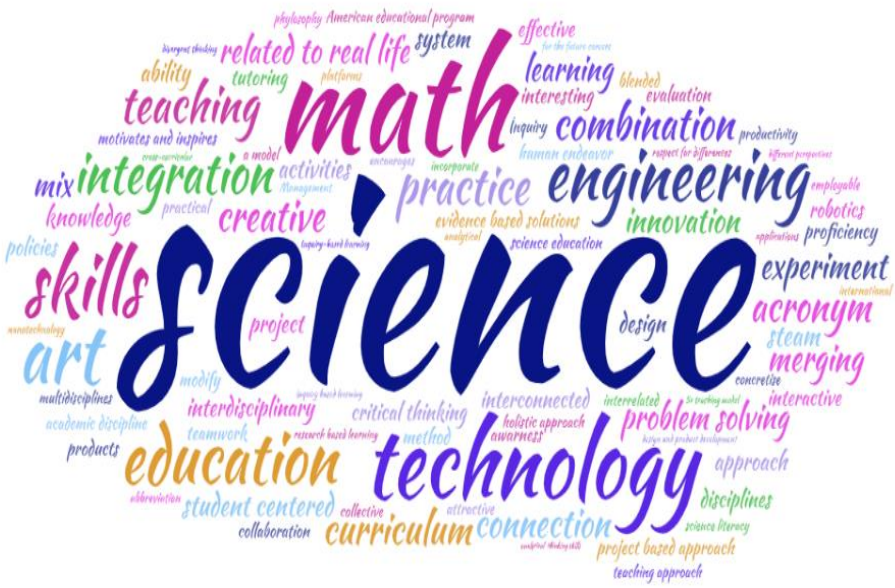
Teachers' opinions are described in the results section, with an emphasis on regional differences and characteristics of the STEM education approach. Key attributes of STEM, according to teachers, are its multidisciplinary nature, its relevance to real-life problems, and the cultivation of 21st-century skills. A general perception that STEM education emphasizes collaborative and process-oriented learning was reinforced by the analysis, which also identified which qualities were deemed unnecessary. Responses varied by region, highlighting the various cultural and educational circumstances that shape teachers' conceptualizations. This highlights the need for methods that account for local differences and needs to enhance the successful integration of STEM education globally.

Results on Teachers' Conceptualizations of the STEM Education Approach

The first step in the research was to generate a word cloud using the data from examining the teachers' responses to the initial research question (Figure 1). Teachers used 91 different words to describe the STEM education approach.

Figure 1

Word cloud for teachers' definition of STEM education



As expected, the words in the STEM acronym, "science (f=157), technology (f=149), mathematics (f=130), engineering (f=120)," were the most mentioned in all regions. The most often used words across all regions are education (f=50), integration (f=31), relevant to real life (f=21), combination (f=20), problem solving (f=16), teaching (f=16), and practice (f=16). Some words were emphasized more frequently. The distribution of these words by region is as follows: "combination" and "approach" in Europe, "integration" and "problem-solving" in the Middle East, "integration" and "teaching" in Asia, "American Educational Program" and "interdisciplinary" in African Francophone, "experiment," "relevant to real life," "skills" and "integration" in African Anglophone.

Results on Teachers' Preferences for Relevant and Irrelevant Characteristics of STEM Education

In the second step of the research, the data obtained from examining the teachers' answers to the second research question were analyzed (Table 2).

The characteristics of STEM education, presented to participants in random order, were classified into two categories: Relevant (R) and Irrelevant (IR). Attributes categorized as R are marked with the initial "R," while those categorized as IR are marked accordingly.

To enhance interpretability, a color-coding scheme was applied. Features identified as R are displayed in pink, while those identified as IR are displayed in blue. The shade intensity corresponds to the frequency with which an attribute was selected by participants. Specifically:

•5–15% = very light tone
•16–30% = light tone
•31–45% = medium tone

•46–60% = dark tone
•61% and above = darkest tone

In instances where no distribution is observed, white coloration is utilized. This gradation enables a visual comparison of the prevalence of attributes across categories, with darker tones indicating higher frequency and lighter tones indicating lower frequency.

Table 2

Teachers' opinions on the relevant and irrelevant characteristics of STEM education

		1	2	3	4	5
		Europe	African Franco phone	African Anglo phone	Middle East	Asia Pacific
R 1.	It is an interdisciplinary approach.					
R 2.	Based on real-life problems.					
R 3.	It is sufficient to integrate at least two STEM disciplines					
R 4.	It supports the development of 21st century skills.					
R 5.	It is a student-centred approach.					
R 6.	It is a process-oriented approach.					
R 7.	It is a skill-oriented approach.					
R 8.	It facilitates the understanding of real-life problems.					
R 9.	It requires using the engineering design process.					
R 10.	It enables students to learn from their mistakes.					
R 11.	Supports group work.					
R 12.	It requires evidence-based decision-making.					

R 13.	The learning process should be planned step by step.					
R 14.	It allows for iterative design processes.					
R 15.	It focuses on problems that have more than one solution.					
IR 1.	It can be applied with a single discipline.					
IR 2.	It consists of laboratory activity only.					
IR 3.	It is a teacher-centred approach.					
IR 4.	It is a product-oriented approach.					
IR 5.	Supports individual work only.					
IR 6.	It is a costly approach.					
IR 7.	These are activities based on robotics only.					
	Percent frequency of reported Rs	5- 15%	16- 30%	31- 45%	46- 60%	>61%
	Percent frequency of reported IRs	5- 15%	16- 30%	31- 45%	46- 60%	>61%

There are five regions included in the research: Europe, African Anglophone, African Francophone, Middle East, and Asia-Pacific. The features most identified as relevant (R) were:

- R2: Based on real-life problems
- R4: Supports the development of 21st-century skills

Teachers from every region highlighted these qualities, demonstrating a general understanding of the value of contextual and skills-based learning in STEM education. They emphasized the importance of STEM education in developing the critical thinking skills required for today's society and being based on real-life problems.

Conversely, the characteristics most frequently deemed irrelevant (IR) included:

- IR4: Product-oriented approach
- IR5: Supports individual work only

These qualities were uniformly minimized in every location, indicating a widespread agreement that isolated individual projects or product outcomes should not be the main focus of STEM education. Collaborative, process-oriented, and interdisciplinary approaches are clearly preferred instead.

In terms of the selection of irrelevant (IR) features, Although the regions had similar or different preferences for some items, it was observed that teachers' preferences from African Anglophone and Europe had similar distribution rates. The lowest selection of IR features was seen in the Asia-Pacific region. The IR selections by African Francophone teachers were also relatively low. In contrast, Middle Eastern teachers selected IR features at higher distribution rates than other regions.

Interestingly, the distribution rates for selecting relevant (R) features showed that European and African Anglophone countries had similar percentages. Following closely were the African Francophone countries, which had slightly lower but comparable rates. The Asia-Pacific region trailed with marginally lower rates than the African Francophone region. Despite selecting a high proportion of IR features, Middle Eastern teachers also chose R features at higher rates than other regions. This suggests that while certain aspects of STEM education are well understood in the Middle East, the high selection of IR features indicates some conceptual misunderstandings.

In sum, this study reveals both global convergence and regional diversity in the perception and implementation of STEM education. While there is considerable agreement on the essential and important elements as well as irrelevant features of STEM education, certain regional differences suggest that they may be culturally, politically, or economically based.

For example, teachers from the African Anglophone regions of Europe and Africa exhibited similar distribution rates in selecting both relevant (R) and irrelevant (IR) features. In contrast, the Asia-Pacific region showed the lowest selection of IR traits, followed by the African Francophone region with slightly higher rates. Interestingly, Middle Eastern teachers also presented a strong understanding of R attributes, although they selected IR attributes at higher rates.

These results highlight the necessity of targeted STEM education programs appropriate for regional settings. It is imperative to create and carry out educational initiatives that respect and include local educational priorities and cultural diversity, as well as follow international best practices. With this strategy, STEM education will be successful, relevant, and able to accommodate the various needs of students from various geographic areas.

Discussion

This study argues that it is essential to correctly understand the concept of STEM education when implementing the STEM education approach. Unsurprisingly, in conceptualizing the STEM education approach, the first thought turns to the words represented by the acronym STEM. This is primarily because the acronym itself is derived from the initial letters of the related disciplines, thereby creating a memorable association. STEM, which stands for "science, technology, engineering, and mathematics," was the most mentioned by teachers in all regions. Similarly, Bartels, Rupe and Lederman (2019) noted that STEM stands for science, technology, engineering, and mathematics as determined by all participating teachers. Furthermore, the most often used words across all regions are education, integration, relevant to real life, combination, teaching, problem-solving, practice and skills. This finding is supported by Breiner, Harkness, Johnson and Koehler (2012), who noted that teachers' conceptualisation of STEM education differs in understanding. The findings of Haddad et al. (2022) highlights the idea that educators should be prepared to think of STEM education as a complex and practical strategy that develops 21st century skills rather than just an acronym.

Radloff and Guzey (2016) identified varying perspectives on STEM education among pre-service teachers. In their study, participants conceptualized STEM education through lenses such as pedagogy, discipline, exclusion, and integration. The study also highlighted regional differences in the frequency of STEM-related terminology used by pre-service teachers. Despite numerous efforts to enhance STEM education within educational systems (Akon-Yamga et al., 2024), teachers' conceptualizations of STEM often diverge, influenced by their instructional methods and interpretations. These differences may result in misunderstandings or misapplications of STEM's theoretical principles in practice. Notably, teachers consistently stress the interdisciplinary nature of STEM education as central to both teaching and learning. The results of this study are congruent with the predefined characteristics of the STEM education approach (Akarsu et al., 2020). Teachers in many regions focus on providing experiences that allow students to apply STEM concepts in real-world contexts (Elmas, 2020). Depending on their instructional approaches and level of knowledge, private school science instructors worldwide have different conceptualizations of STEM education (Thibaut et al., 2017).

Ring, Dare, Crotty and Roehrig (2017) found that teachers' STEM integration models were related to real-world problem-solving as context, STEM as separate disciplines, and STEM as an acronym. According to Zhan, Shen, Xu, Niu, and You (2022), STEM education is influenced by different nations' social, cultural and economic issues. Although Western countries emphasized 'educational equity' and 'disciplinary integration,' Eastern countries emphasized 'humanistic leadership' and 'cultural integration' in STEM education. To successfully incorporate STEM education in the classroom, instructors must have a solid understanding of STEM disciplines and their approaches to integration (Fathy, & Malkawi, 2022).

The study further revealed that while teachers from different regions commonly describe STEM education as being "based on real-life problems" and emphasizing "the development of 21st-century skills," these are seen as relevant features. However, there is a widespread misconception that STEM education is predominantly a "product-oriented approach" and "supports individual work only," considered the most prominent irrelevant features. STEM education may be perceived by teachers as a product-oriented approach, as it is often associated with project competitions, robotics tournaments, or engineering prototypes.

Similarly, the lack of emphasis on teamwork and collaboration in the context of STEM education may have created the perception among teachers that they are supporting students' individual success ultimately, students get a score or grade on their personal report cards. In this context, pre-service training can be provided to teachers and prospective teachers to support the effective implementation of STEM education in classrooms. In their study, Khuyen et al. (2024) provided STEM training to pre-service teachers and found that, as a result, the lesson plans developed by the pre-service teachers shifted from a product-oriented to a process-oriented approach. Although the multidimensional structure of STEM education makes it difficult to define for practice (Dare et al., 2022), there are some essential characteristics on which STEM education is curated. The characteristics of the STEM education approach include being based on real-life problems, supporting skill development, being process-oriented rather than product-oriented, and supporting group work and peer solidarity (Elmas & Adiguzel Ulutas, 2022). Roehrig, Dare, Ellis, and Ring-Whalen (2021) stated that one of the seven features of integrated STEM education is the development of 21st century skills. Besides, numerous studies demonstrate that the STEM education approach fosters the development of skills such as problem-solving, effective communication, collaboration, leadership, creativity, and analytical and critical thinking, which are essential components of 21st century skills (Elmas & Gül, 2020; Stehle & Peters-Burton, 2019; Uttal & Cohen, 2012). In this context, teachers appear to establish appropriate associations with the key characteristics of the STEM education approach. Their views on integrated STEM teaching are positively linked to both their professional development and the personal value they attribute to science (Thibaut et al., 2017). Dare, Keratithamkul, Hiwatig and Li (2021) further noted that all participating teachers viewed STEM education through an integrated lens, recognizing its potential to develop 21st century skills and motivate students by engaging them with real-world challenges.

Conclusion

The findings of this research offer insightful data about teachers' understanding and attributes surrounding STEM education, which can help schools implement an integrated STEM education approach (Chaya, 2023; Nayem & Hossain, 2023; Permanasari et al., 2021; Said et al., 2023). These divergent interpretations of the STEM education approach highlight the need for further research to raise awareness and promote the widespread adoption of its core and well-established characteristics.

Moreover, given the widespread misconceptions about the characteristics of STEM, teacher training programs should place greater emphasis on process-oriented, collaborative, and interdisciplinary learning approaches. Professional development programs should ensure that teacher candidates gain competence in planning, implementing, and evaluating STEM applications. Achieving a consensus on a unified understanding of STEM education and advancing based on these shared principles will ensure effective skill acquisition among students.

Further research in STEM education could explore several critical areas to enhance both the understanding and practical application of the STEM education approach. One potential focus is conducting longitudinal studies that examine teachers' professional development and classroom practices over extended periods of time. Such research would provide valuable insights into how educators conceptualize and implement STEM education, allowing for a deeper understanding of how these practices evolve. Additionally, exploring the specific challenges and opportunities teachers face in different educational settings is crucial. While the current study involved participants from multiple nations, future research could benefit from comparative studies investigating differences between various educational contexts, such as urban versus rural schools or public versus private institutions. These comparisons would yield a more nuanced and comprehensive perspective on how STEM education is adopted and applied in diverse environments. Furthermore, examining the influence of teachers' backgrounds, resources, and student demographics on STEM education outcomes could reveal important variables that shape instructional strategies and inform effective teaching practices. By expanding research in these areas, scholars and policymakers can work towards more effective and equitable STEM education practices, ensuring that students from all regions and institutions gain access to the skills and knowledge necessary for success in the 21st century.

In addition, it would be beneficial to explore how technological advancements, such as artificial intelligence and machine learning, can further support STEM education. Integrating emerging technologies into the curriculum not only reflects the interdisciplinary nature of STEM but also equips students with the tools to address complex real-life problems. Similarly, investigating the role of collaboration between schools, industries, and communities in fostering innovation in STEM education would provide insights into how external partnerships can enhance the learning experience. Ultimately, striving for a more unified and comprehensive approach to STEM education, supported by rigorous research and practical applications, will be vital in advancing both teacher professional development and student academic success in the evolving educational landscape.

Limitations

The coding process was conducted independently by two researchers, followed by discussions to reach consensus. However, no quantitative measure of inter-rater reliability was calculated, which constitutes a limitation of this study. Only teachers with experience in STEM education were included in the sample for this study. This situation may introduce potential selection bias, as the findings do not represent teachers who are unfamiliar with STEM.

Declaration of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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