NPRC Journal of Multidisciplinary Research
Volume 2, Issue 4, April, 2025 Pages: 160-178
ISSN: 3059-9148 (Online)
DOI: https://doi.org/10.3126/nprcjmr.v2i4.76925

Approaches to Stem Education around the World, What We can Learn from Them

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Review articles
Received: March 11, 2025 Revised & Accepted: April 29, 2025

Abstract
The article commences with a historical review of STEM education, followed by a discussion of its implementation across various nations worldwide. The objective of the research is to identify and categorize the diverse approaches to implementing STEM education, with a view to establishing standards that can serve as a model for its introduction in other countries. The primary conclusion of the research is that while STEM education can be incorporated into a nation's educational system, it does not necessitate the entire curriculum being based on it.
Keywords: STEM education, curriculum, STEM approaches

Introduction
The initial link between disparate scientific disciplines, and by extension STEM, can be traced back to Ancient Greece, where Aristotle and Hippocrates devoted themselves to the study of their immediate environment. The conceptualization of mathematics as a scientific discipline can be traced back to the works of Pythagoras, while its integration into engineering and infrastructure construction followed shortly thereafter. The subsequent industrial revolutions that ensued precipitated a profound transformation in the everyday landscape and, by extension, the educational sector (Unesco & Boon, 2019). During the Second World War, the military and scientists collaborated to apply the new technologies of the era, and this

collaboration was also necessary to end the war. This example demonstrates the application of STEM, but not in education (Widya, Rifandi, & Rahmi, 2019).

The acronym STEM, an abbreviation for Science, Technology, Engineering and Mathematics, signifies a pedagogical approach that integrates the principles of the aforementioned disciplines, namely physics, chemistry, biology, geology, technology, mathematics and engineering. In this paradigm, students are encouraged to approach each problem through an interdisciplinary lens, a method that fosters the development of multiple skills. The overarching objective of STEM education is to cultivate professionals who possess the capacity to devise innovative solutions by synthesizing knowledge from diverse fields.

The necessity to enhance the teaching of science and mathematics in the United States has been a matter of pressing concern since the early 1980s. This has given rise to a focus on STEM (Science, Technology, Engineering and Mathematics) education, as evidenced by the National Science Foundation's (NSF) numerous references to this subject in its reports (Breiner, Johnson, Harkness, & Koehler, 2012). The impetus for these changes stems from the global economy, which is undergoing significant transformation (Kenned & Odell, 2014), as well as the need to maintain national economic competitiveness (Maass, Geiger, Ariza, & et.al., 2019) . By the close of the decade, a plethora of publications by various associations articulated their objective of fostering scientific literacy among the American populace. During the 1990s, the endeavors to fortify the science discipline garnered support from associations representing elementary, secondary, and higher education teachers. The culmination of these endeavors was the formulation of innovative curricula in science, mathematics, engineering, and technology (SMET) (Breiner, Johnson, Harkness, & Koehler, 2012) . The advantages of this type of education were such that it was elevated to the top of the U.S. policy agenda (Blackley & Howell, 2015). In order to ensure the success of the introduction of this new form of education, it was deemed necessary to inform teachers, especially those who teach at undergraduate level (National Science Foundation, 1996).

Concurrently, and extending up to the first years of the 21st century, research across multiple countries has documented a decline in the pursuit of these disciplines by secondary school students, accompanied by a decline in admissions to universities to study, primarily, physics and mathematics. Specifically, within the United Kingdom, between 1990 and 2008, there was a 49% decline in physics enrolment and a 26% decline in chemistry enrolment (Bøe, Henriksen, Lyons, & Schreiner, 2011).

The acronym STEM (Science, Technology, Engineering and Mathematics) began to be used in the early years of the 21st century, as the word SMET was considered to resemble the word smut (smoke). In order to make it clear that the union of sciences is done with the aim of strengthening the educational system and that no reference is made to any other field, the term STEM Education was used. In 2005, Virginia Tech University established the first curriculum with a central theme of STEM education (Integrative STEM Education) (Sanders, 2009). [9]. By the close of the decade, a rapid increase in the initiation of new curricula on the subject of STEM and the corresponding doctoral theses was observed (Moore & Smith, 2014). [10].

From 2007 onwards, the significance of STEM education as a catalyst for success, both in the acquisition of knowledge during school years and in the development of professional skills for future careers, began to be recognized (Breiner, Johnson, Harkness, & Koehler, 2012). The influence of the arts (primarily literature) and social sciences on the scientific field was first documented in the literature by Yakman G. in her 2008 thesis. Notably, she introduced the term STE@M, where the middle @ symbolizes the arts, and was the first to propose an educational framework integrating the sciences and the arts. It is important to note that the term arts do not exclusively refer to the fine arts, but also encompasses a wide range of skills not included in scientific disciplines (Yakman G. , 2008).

In 2009, the University of Minnesota established the University of Minnesota STEM Education Center with the objective of enhancing this particular type of education (Moore & Smith, 2014). In 2010, reference was made to the misunderstanding of many students regarding STEM education, who, despite the numerous applications of engineering and technology in everyday life, when referring to STEM, primarily associate it with mathematics and natural sciences. The article further elucidates the primary objective of STEM education as fostering a profound comprehension of the interplay between natural laws and human accomplishments, while concomitantly enhancing technological literacy. It is imperative to re-evaluate the role of engineering, recognizing its nexus with competencies such as problem-solving and the generation of innovative solutions, which are indispensable in both professional and national contexts (Bybee R. W., 2010). In 2011, John Maeda, representing the Rhode Island School of Design (RISD), articulated a strong advocacy for the transition of STEM to STEAM, a position informed by his own multidisciplinary background as an artist, graphic designer, computer scientist, and educator (Maeda, 2011). The integration of arts into STEM has been posited as a means to enhance the comprehensibility of information and the aesthetic appeal of products (Piro, 2010). In 2011, the Korean Ministry of Education adopted a similar approach by proposing the integration of arts into STEM learning, thereby transitioning to a STEAM-based educational framework (Widya, Rifandi, & Rahmi, 2019).

In 2012, Yakman G. & Lee H. made a compelling case for the inclusion of the arts in a publication concerning STEM education in Korea, arguing for the transformation of STEM into STEAM. This transformation, they asserted, would be informed by the rich philosophical, psychological and sociological traditions found in the arts sector. They contended that the arts had played a significant role in the development of human civilization, and that this should be recognized as a fundamental aspect of any comprehensive STEAM education. This paper proposes a novel definition for each constituent of the acronym, representing a significant advancement in the field (Yakman & Lee, 2012). The integration of fine arts has been demonstrated to foster students' creativity, a skill that is increasingly recognized as a vital component of 21st-century learning (Aguilera & Ortiz- Revilla, 2021). Furthermore, the amalgamation of convergent thinking, which is imperative in the context of scientific problem-solving, with divergent thinking, which characterizes humanities and artistic disciplines, has been shown to be a catalyst for innovation (Yakman & Lee, 2012). The integration of non-

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STEM disciplines fosters the development of imagination and creativity, which have frequently been the catalyst for scientific innovation (Shukshina, et al., 2021). In 2013, the International Council of Association for Science Education (I.C.A.S.E.) in Kuching emphasized the necessity to link STEM education with contemporary issues, such as environmental protection and sustainability (EDUCATION, 2013). This declaration observed a trend of science being more outward-looking towards society, offering a novel perspective on this type of education. It also reflected the need to connect what students can learn from scientific disciplines with issues that concern both ethical and humanitarian factors. While the connection with the seventeen UN sustainability goals is clear, an extension of this connection is the cultivation of moral values and feelings such as social justice and equality (racial and gender).

In 2015, the report on the US education strategy stated that mathematics, natural sciences, technology and engineering should be regarded as interconnected concepts, given their relevance in everyday life (Council, 2020).

In 2019, the UNESCO International Bureau for Education (IBE) emphasized the necessity of integrating STEM disciplines with non-STEM ones, acknowledging the blurring of boundaries between the two disciplines in the context of the ongoing Industrial Revolution 4.0. The report also underscored the importance of aligning educational goals with the 2030 Sustainable Development Goals. It is noteworthy that the term STEM has evolved to encompass a broad spectrum of specialties within the professional sector, extending beyond the traditional scientific domain (Unesco & Boon, 2019).

The purpose of this article is to identify the interest of educational programs around the world in STEM education, in order to identify the ways in which it is implemented in each country. The ways in which it is implemented will then be grouped. In this way, the article aims to identify best practice in STEM education. Through a comparative analysis of the data collected, an attempt is made to answer the question of whether it is necessary to be part of the secondary school curriculum or whether it can function as a support in any other curriculum.

Research methodology

The method used to write the article was documentary research. Google Scholar, Sematic Scholar and MDPI databases were searched for articles. Two complex searches were carried out in each of these engines. The first with the following keywords (STEM EDUCATION) AND (CURRICULUM). The second with the following keywords (STEM EDUCATION) AND (SECONDARY SCHOOL). For Greece, a more extensive search was carried out, analyzing the new curricula expected to be implemented in the near future.

Of the articles that appeared, only those that referred to specific ways of implementing STEM education in their reference country were accepted. While articles related to teachers' views on STEM education, specific pedagogical methods that improve the results of such education, as well as articles related to the advantages and disadvantages of this type of education, were not included.

In total, 28 sources were examined that related to applications of STEM education in different countries around the world.

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STEM Education in Different Nations

A substantial number of studies, predominantly in developed countries, have been conducted to evaluate the adequacy of STEM education received by students. The comparison of the findings from these studies is challenging due to the varying contexts of each nation, the divergent policies enacted by policymakers regarding STEM education, and the differing models of equal participation between men and women (Bøe, Henriksen, Lyons, & Schreiner, 2011). The implementation of STEM education varies significantly across countries, necessitating a country-specific report on the implementation method. In the USA, the STEM education curricula are founded on three pillars: the application of scientific and engineering practices, and the integration of science with engineering (Roehrig, El-Deghaidy, García-Holgado, & Kansan, 2022).

Table 1 shows the applications of STEM education by country, as derived from the literature review. The table also shows the reason for implementing this education, the objectives and the problems encountered during its implementation.

Table 1 STEM approaches per Nation

SOURCES	COUNTRY	Application timeline	Reason/Purpose	Way	Problems
(Roehrig, El-Deghaidy, García-Holgado, & Kansan, 2022), (Xie, Fang, & Shauman, 2015), (McDonald, 2016), (Tang Wee Teo, STEM Education Landscape: The Case of Singapore, 2019).	U.S. A			There are four types of school - three of which have a focus on STEM education, each with a different approach.	Inequalities in access to such education by gender and sex
(Widya, Rifandi, & Rahmi, 2019)	Saudi Arabia				Teachers' readiness to implement it.
(Widya, Rifandi, & Rahmi, 2019)	Malaysia	Integration work commenced			Inadequate teacher training.

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		in the year 2017.			Lack of technological resources. Designing an appropriate curriculum.
(Widya, Rifandi, & Rahmi, 2019)	Korea		Despite high PISA scores, they didn't want to pursue careers in the following areas		Teacher workload. The time needed to prepare the course. Familiarisation with the use of new equipment.
(Quan, 2020), (Wong & Shih, 2022), (Leung, 2020)	China		Promoting STEM education and innovation It has been argued that STEM education is linked to industrial development.	Establishment STEM Education Innovation Center	
			To develop STEM in all of China's provinces, not just in the more developed ones.	Implementation of an Action Plan Education 2029.	Insufficient knowledge of teachers. Poor equipment.
		2017	STEM becomes obligatory.	Science curriculum review.	
	Province Zhejiang	2018	To address the key problem of implementing STEM, which is related to what teachers know.	15 teacher training programs.	
	Hong Kong	2015	Development of students' skills.	Primary and secondary school introduction to STEM.	It was the way the problems were solved, so it was reproducing the same model, it wasn't innovating.

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				Encourage student participation: A. in extra-curricular activities B. Competitions and exhibitions C. Cooperation with organisations.	STEM was identified with the use of ICT.
(Schiepe-Tiska, Heinle, DÃ¼mig, Reinhold, & Reiss, 2021)	Germany	2000	PISA poor performance.	Teachers were given the freedom to move away from the curriculum to implement STEM by working on projects.	
(Farwati, et al., 2021)	Indonesia	From 2014	Cooperation with Universities	Increasing implementation and interest between 2015-2020.	
(Tang Wee Teo, STEM Education Landscape: The Case of Singapore, 2019), (Gonzalez-Perez & Ramirez-Montoya, 2022), (Tang Wee Teo & Tang Wee Teo, Singapore Math and Science Education Innovation, 2021).	Singapore	2005	Identifying gifted students	The National University establishes the High School of Mathematics and Science	
		2010	Application to everyday life problems.	School of Science and Technology established in collaboration with the Faculties of Engineering.	
		2013		Primary and secondary school	

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				participation in STEM programs.	
				Support for the participation of students from STEM schools in competitions.	
				Funding of teacher training programs in all schools.	
(Delivering STEM skills for the economy., 2017-2019), (Darwish & Darwish, 2019)	United Kingdom	2017-2018	The development and strengthening of the economy.	47th Parliament Reports	
			Strengthen the teaching of science and mathematics.	Create a National STEM Directorate responsible for implementing 11 programs.	
(Yata, Ohtani, & Isobe, 2020)	Japan			Using STEM, but not in a strict context.	Teachers' misinterpretations of its implementation.
(El Nagdi & Roehrig, 2022)	Αίγυπτος	2011	Upgrading education. Acquiring 21st century skills. Creating competitive professionals.	Establishing the 1st STEM School.	
		2019		There were 19 schools with STEM subjects.	
				The collaboration of schools with Universities and Research Centers was supported.	
(Roehrig, El-Deghaidy, García-Holgado, & Kansan, 2022)	Spain		Mathematics, Science and Technology are supported	Curriculum based on the European Reference Framework for Key Competences for Lifelong Learning.	Engineering is being sidelined.
				Making individual efforts.	

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(Sen, Ay, & Kiray, 2018). (Roehrig, El-Deghaidy, García-Holgado, & Kansan, 2022)	Turkey	2014	Report on Demand for STEM Professions Published by Turkish Industry and Business Association (TUSIAD).	Organization of STEM festivals across the country by University Institutions	
		2016	Acquisition of 21st century skills.	Curricula are enriched to implement STEM.	
(Shukshina, et al., 2021)	Russia	2014	Mathematics and science developed in parallel.	Actions in support of engineering, mainly through robotics.	
				Providing all schools with the necessary resources without delay.	
			Developing skills like collaboration, experimentation, assembly.	Universities and Technological Institutes to create STEM Parks.	
			Teacher training support.	Create STEM postgraduate programs.	
(DeCoito, 2016)	Canada			Individual programs in different provinces were funded by universities and organizations.	
(Milton & Daniel Clark, 2017) (Pugliese & De Macedo Santos, 2022)	Brazil			The emphasis is on maths and science being taught as one subject.	The country's economic situation makes it difficult to implement STEM.
				Inclusion in the STEAM curriculum, a public call was made to collect educational materials.	

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(SEV, 2021), (Official Gazette of the Government of the United Kingdom B/3567, 04/08/2021), (Institute of Educational Policy-Greece, 2023)	Greece			Private schools are particularly involved in STEM.	Strict curricula. Reduced prestige of the teaching profession. Inability to assess students.
				Actions are carried out by private companies and organizations (e.g. Educational Robotics Organization - Cosmote, Generation Next - Vodafone) and collective associations (e.g. Union of Greek Physicists).	
		2021	Developing 21st century, mind, and life skills.	Implementation of the "Skills Workshops" course in elementary and high schools.	
		The expectation was that it would be in place by 2023-2024, it hasn't been in place, but it is an expectation.	Development of 21st century skills, orientation towards science, innovation, integration of everyday issues. Acquisition of metacognitive skills.	Implement new curricula that make clear reference to STEM education.	
(Tomková, 2025)	Slovakia	2023	Support for the efforts started in 2008. Initial aim: to improve PISA results. Ultimate goal: to develop	Education reform "Education for the 21st century". The implementation of STEM education will be promoted.	Teachers' expertise in science and mathematics. Pupils do not initially show

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			students' skills with an emphasis on critical thinking.		interest in scientific careers.
(Terziyski, 2024)	Bulgaria		Encourage students to participate in extra-curricular activities, including Student Olympics and other international competitions.	Ministries of Education and Culture and non-governmental organizations.	
			Participate in extracurricular STEM activities led by working researchers.	Fund the 'Science and Education for Smart Growth' operational scheme.	
			Encourage students to get involved in extracurricular activities.	Founder member of many international student contests.	
			Cultivation of 21st century skills in students and preparation of them to be competitive professionals.	Modification of curricula in order to focus students' interest in individual areas, from the early school years onwards.	
		2018	Improve STEM education and skills across Europe.	Inclusion of the country in the EU STEM network. Policy makers, educators and industry work together to achieve this goal through the creation of collaborative networks.	
		2022	Developing an integrated educational environment that	Establish a National STEM Centre, an independent legal entity with public funding.	

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			supports each area.		
(Blagdanić & Ristić, 2025)		2023-2025		Erasmus Plus STE(A)M in primary education: Mission Possible Programme (2023-2025). Development of short scenarios by integrating two or more subjects.	
(Blagdanić & Ristić, 2025)	Σερβία	2023-2025	Teacher training in STEAM/STEM scenarios. Strengthen learning outcomes through problem solving and its interdisciplinary approach. Develop soft skills in students.	Erasmus Plus STE(A)M in primary education: Mission Possible Programme (2023-2025)	
				Training programs for teachers.	
(Blagdanić & Ristić, 2025)	Slovakia			Erasmus Plus STE(A)M in primary education: Mission Possible Programme (2023-2025)	
(Kumar & Kulshrestha, 2025)	India	2020	To enable students to face any problem in their professional life.	The National Education Policy (NEP) promotes robotics and coding in the curriculum.	
		2016	Bridging the gap between theory and practice through the use of cutting-edge technologies such as 3D printers and robots, and fostering a culture of	Atal Tinkering Lab (ATL) Program	

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			innovation and entrepreneurship among students. Improving STEM education overall.		

Discussion

A comparative analysis of data on the implementation of STEM education in different countries reveals a universal recognition among education policymakers of the need for students to acquire 21st century skills. This need is compounded by the imperative for students to develop the capacity to deal effectively with the challenges they face in their daily lives. Consequently, there is a consensus that STEM education has the potential to make a significant contribution to this endeavor.

Between 2014 and 2017, a significant number of countries appear to have initiated a shift towards STEM education, including Malaysia, China, Hong Kong, Indonesia, the United Kingdom, Japan, Turkey and Russia. Earlier examples include Germany in 2000, Korea in 2011 and Singapore in 2005. As the 21st century progresses, the majority of nations are seeking to move towards STEM education, recognizing the need for citizens to have the necessary skills to contribute to the economic development of their respective countries. It is noteworthy that the aforementioned transition periods coincide with the development of STEM education in these countries. The I.C.A.S.E. 2013 event was an important milestone in this regard, as it highlighted the link between STEM education and not only skills development, but also sustainability. Consequently, the subsequent adoption of STEM education by many countries after 2014 cannot be seen as a mere coincidence. It is worth noting that for many countries, the results of PISA served as a catalyst for the introduction of STEM education. For example, Germany introduced STEM education after its poor performance in the 2000 competition, while Korea has successfully combined STEM education with high performance in the competition. Another factor that seems to be related to the implementation of STEM education is the economic situation of the country, which is not surprising given the logistical demands of fully equipped laboratories and classrooms. Brazil, for example, recognizes the importance of STEM education but is unable to implement it due to a lack of appropriate logistical support. Conversely, Russia's strategic shift towards STEM education, with a strong emphasis on robotics and engineering, has been accompanied by the provision of essential equipment to educational institutions, a measure in line with the country's economic capacity.

Another way in which the approaches of these nations differ is in the integration of STEM education into their respective curricula. For example, Turkey, China and Singapore have changed their curricula to ensure that all students have access to STEM education. In contrast, Germany has not changed its curricula, but has made them more flexible to allow for the integration of STEM education in schools.

In Greece, the last revision of the curricula took place in 2023, with the aim of implementing them from the 2023-2024 school year. This represents a later start to the process compared to the countries mentioned above. A common theme in all curricula is the emphasis on the acquisition of 21st century skills, metacognitive skills, problem solving skills and higher order thinking skills. It is noteworthy that STEM education has the potential to contribute to these goals. However, the references to STEM education are mainly to be found in the technology course, which is offered at all levels of secondary education, but only for one hour per week. In addition, there are explicit references to STEM education in the Physics course at primary, middle and high school level, with a focus on promoting students' recognition of the interconnectedness of mathematics with other disciplines. An alternative approach to STEM education, emulated in countries such as Egypt, Singapore and the USA, involves the establishment of dedicated STEM schools. The merits of this approach lie in the availability of specialized teachers who can impart knowledge in the required methodologies. However, this approach is not without its drawbacks, particularly in terms of its ability to ensure equitable access to STEM education for all students.

In Hong Kong, Spain, Canada, Indonesia and Bulgaria, the integration of STEM education is mainly associated with extracurricular activities, with its implementation reinforced by external factors such as universities and organizations. Some of these extracurricular activities include participation in student competitions, which is in line with our approach. Student competitions organized by private bodies are supervised by the Ministry of Education and Religious Affairs. It is noteworthy that the majority of these competitions are related to robotics rather than STEM education as a whole.

In the academic context, it is already accepted that any change and implementation of an education system must be based on the wider social, cultural and economic context in which it takes place (Niu, Xu, & Yu, 2025; Mahapoonyanont & Songsang, 2024; Kelly & Kotthoff, 2017; Wang, Perry, & Malpique, 2023). Similarly, in STEM education it is not enough to copy a successful educational model, but other socio-economic factors must also be taken into account.

Successful implementation of STEM education requires the inclusion of the experiences, cultural and social characteristics of the students involved (Mansour, 2024). Factors that influence the potential of secondary school students for future careers in STEM fields include

- Exposure to STEM education from the early school years (Mansour, 2024; McDonald, 2016; Bybee R. , 2010; Dernadeta, Simbolon, Emilldan, & Melodic, 2022) or more generally in or out of school (Ribeirinha, Baptista, & Correia, 2024) .
- Personal interests (Mansour, 2024; SEV, 2021)
- Motivation (Mansour, 2024; Ribeirinha, Baptista, & Correia, 2024)
- Participation in out-of-school activities (Mansour, 2024) (Norris, Taylor, & Lummis, 2023) (Ab Ghan, Awang, Ajit, & Rani, 2020) (Niu, Xu, & Yu, 2025)
- Students' self-confidence (Mansour, 2024)

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- Stereotypes about STEM career preferences (Mansour, 2024; Dernadeta, Simbolon, Emilldan, & Melodic, 2022; Ribeirinha, Baptista, & Correia, 2024)
- Cultural factors (ethnicity, religion) (Mansour, 2024)
- Social factors (family) (Mansour, 2024; Dernadeta, Simbolon, Emilldan, & Melodic, 2022; Arsad & Heong, 2024; Ribeirinha, Baptista, & Correia, 2024)
- Gender, with women under-represented (Mansour, 2024; Dernadeta, Simbolon, Emilldan, & Melodic, 2022; Vasconcelos, Bigotte, Marques, & Almeida, 2022; Arsad & Heong, 2024; Ribeirinha, Baptista, & Correia, 2024)
- Students' economic status (Arsad & Heong, 2024; Ribeirinha, Baptista, & Correia, 2024) .

The large number of these factors on which the success of STEM education depends justifies the many and varied approaches that have been taken. Moreover, the set of these factors shows that there is no single 'right' way to implement STEM education. Each country, after first analyzing data related to social, cultural and economic factors, can proceed with the appropriate integration of STEM education.

Conclusion

STEM education has unquestionably garnered the global interest of educational systems. Due to its inherent interdisciplinary nature, it is evident that it can be applied in numerous forms. Implementation of STEM education is expected to yield positive results in terms of enhancing students' 21st century skills and their subsequent engagement with STEM disciplines.

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