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STEM Education: A Global Imperative for National Advancement and Sustainable Development

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ABSTRACT

STEM education is crucial for nations aiming to develop knowledge-based economies and enhance global competitiveness. To effectively leverage 21st-century technological advancements, safeguard national security, and address global challenges such as climate change and food insecurity, a significant improvement in the quality of STEM education policies and practices is essential. Successful implementation requires a thorough understanding of STEM's core principles, philosophical foundations, practical applications, and relevant policy frameworks. This critique paper examines the status of key strengths and weakness of the diverse STEM education policies and practices implemented across developed nations. It intends to address the global knowledge and awareness deficit and improve understanding, about the importance of strategically investing in high-quality STEM education, particularly among developing countries.

Keywords: global imperative, national advancement, STEM education, sustainable development

INTRODUCTION

The innovative fields of Science, Technology, Engineering, and Mathematics are long-standing human achievements. They were developed as essential tools to understand and interact with our natural, physical, and social worlds. Although these disciplines have traditionally been taught using a monodisciplinary approach in curricula and policies globally, there is a growing and creativity-driven global interest in integrated STEM approach (Kwon & Lee, 2025). As noted by Leung (2020) and Moemeke (2026), this shift necessitates a fundamental change in educational paradigms, new pedagogies, curricula, policies, and practices. Crucially, each nation's implementation of integrated STEM must be tailored to align with its specific cultural, historical, economic, political contexts, and values. The principles of robust STEM education are universally applicable for national advancement.

This move toward integrating STEM disciplines, however, requires a significant shift in mindset among students, teachers, and society. It demands a transition from a subject-specific focus to an interconnected view of both learning and career development. According to English (2016), Lee and Lee (2022), Li (2014), and Putra and Narulita (2023), combining multidisciplinary, interdisciplinary, and transdisciplinary approaches with mono-disciplinary ones is proven to enhance STEM education. As Fomunyam (2020) study, this integrated model is essential for fostering key student skills, such as creativity, critical thinking, communication, and collaboration. It significantly reduces real-world performance challenges. Ultimately, the goal of this paradigm shift is to cultivate a highly skilled workforce capable of meeting global labor market demands. This in turn drives a nation's economic and cultural advancement and influences globalization (DeCoito, Steele, & Goodnough, 2016; Kwon, Capraro, & Capraro, 2021; Miao, 2023).

Due to the inherent interconnectedness of the components of STEM, it has become essential to shift from fragmented, mono-disciplinary instruction and mindset to integrated STEM education to effectively meet the challenges of the 21st-century (Kwon & Lee, 2025; Moemeke, 2026; Panqueban et al., 2025; Rumjaun, Atchia, Bholah, & Molefe, 2024). Research (e.g., Panqueban et al., 2025) confirms this integrated approach develops the necessary modern skills and is crucial for global development. However, this paradigm shift faces a critical research gap: there is a significant lack of critique on comparative studies providing clear and easily implementable frameworks. Specifically, model texts are scarce in offering a consolidated and critical review of how countries have overcome the structural, pedagogical, and policy hurdles required to transition from a mono-disciplinary to a trans-disciplinary approach. Adaptation of this integrated approach to diverse local, cultural, economic, and political contexts is a particularly critical issue. The main challenge, therefore, lies in reconciling the global consensus on the necessity of integrated STEM education with the severe scarcity of properly evaluated and contextually adapted implementation models needed for its success.

Furthermore, there is a significant knowledge gap regarding the tangible link between specific integrated approach models and empirically verifiable sustainable development outcomes. The goal of integrated approach is to develop a competent workforce that satisfies global market demands and positively influences globalization. However, there is a critical lack of robust and long-term studies that decisively evaluate and compare the effectiveness of various integration strategies. This relates to tangible national economic growth, cultural enrichment metrics, and the successful achievement of specific Sustainable Development Goals (SDGs). This gap makes it challenging for policymakers to identify the necessary evidence-based and high – impact strategies. These parameters are required to fully leverage STEM education as a genuine driving force for sustainable national development. Therefore, this research intends to make a unique contribution by presenting a comparative analysis of STEM education policies and practices across nations, from pioneering countries like the USA to economically advanced nations.

This study aims to address the global knowledge and awareness deficit and improve understanding of the importance of strategically investing in high-quality STEM education globally, particularly among developing countries. This is achieved by analyzing the strengths and weaknesses of the broad spectrum of policies and practices associated with STEM education in developed nations.

Research Questions

- What are the key strengths and weakness of the diverse STEM education policies and practices implemented across developed nations?
- To what extent do the current STEM education policies and implementations practices of developed nations effectively address the global knowledge-based economic demands and the persistent shortage of qualified STEM professionals?
- How can an analysis of successful national-level STEM initiatives inform strategic policy adaptation to enhance STEM knowledge and awareness in other global contexts?

LITERATURE REVIEW

The Evolution of STEM: Concepts, Hierarchical Integration, and Global Implementation Challenges

The STEM education topic is highly timely because the global economy is increasingly knowledge-based. The other reason is that nations worldwide are struggling to meet the rigorous demands of the global labor market due to persistent shortages of qualified STEM professionals. This problem, coupled with the documented gap between the goal of high-quality STEM education and its actual implementation, creates an urgent need for action. Therefore, Dillon and Wong (2025) discussing the origin, evolution, development, and related concepts of STEM is essential. We also need to examine the various teaching and learning approaches, ranging sequentially from the disciplinary to multidisciplinary, interdisciplinary, and trans-diciplinary. This structured comparative review offers a model for national strategic adaptation, showing countries how to implement STEM initiatives within their unique cultural, historical, and economic contexts.

A detailed analysis of the comprehensive nature of STEM education will follow, supported by research evidence. The acronym STEM (Science, Technology, Engineering, and Mathematics) evolved from SMET (Science, Mathematics, Engineering, and Technology) in the 1990s. The USA championed the term in the 2000s to boost economic growth and security (Chesky & Wolfmeyer, 2015; Shanahan, Carol-Ann Burke, & Francis, 2016). Surprisingly, public familiarity with STEM remains low, even in its country of origin and in places like Singapore (Lee & Lee, 2022). Despite its pioneering role, the USA lags in knowledge-based economic development compared to Canada, Germany, and Finland. This gap stems from other nations' stronger investment in STEM. As reported by a 2022 report from National Taiwan Normal University, this highlights a global struggle: while advanced nations face significant hurdles, developing countries encounter even greater challenges in effective STEM implementation.

The integrated STEM education approach was introduced globally to address the demand for a skilled workforce by boosting students' interest in mathematics and science. This hands-on approach aims to significantly develop talent across these fields and increasing student engagement with technology, engineering, and the arts. The USA pioneered this concept following the Soviet Sputnik launch (Fomunyam, 2020; Lee & Lee, 2022). However, many experts stress that each region must redefine STEM within its unique context (Krug and Shaw, 2016; Shanahan, Carol-Ann Burke, & Francis, 2016). For example, Canada views STEM as a boundary object with broad benefits for all communities, while Germany uses the term MINT (Mathematics, Informatics, Science, and Technology (Lee & Lee, 2022). The core implication is clear: the unity, integration, and co-operation among these related fields yield for greater benefits for society than individual disciplines alone.

The evolution from STEM to STEAM (Science, Technology, Engineering, Arts and Mathematics) marked a pivotal educational shift. In 2007, the "A" for the Arts was added to recognize the crucial role of creativity and design thinking in technical fields. This shift aimed for a more holistic learning approach, acknowledging that innovation thrives at the intersection of diverse disciplines. However, persistent challenges hinder effective STEM delivery. Key literatures highlights the urgent need to redesign the curriculum for relevance and engagement (Lee & Lee, 2022; Li, Forbes, & Yang, 2021; Suhirman & Prayogi, 2023). We must also address the shortage of qualified educators through robust training and integrate new learning strategies with technology dynamic delivery. Strengthening the linkage between schools and higher education is critical for seamless transitions. Other essentials include developing balanced assessment strategies, advocating for increased government investment, fostering connections between education (formal, non-formal, and informal) and industry, and actively addressing equity issues. This paper's recommendations are directly informed by these crucial focal points, drawing insights from successful implementation globally.

Educators must foster a conducive learning environment where students develop a genuine interest and positive attitude toward STEM. This enables them to effectively apply these concepts daily. Simultaneously, raising community awareness is crucial and requires all educational stakeholders, especially teachers, to be involved. Educators must emphasize effective and innovative teaching methods. However, the global shortage of qualified STEM teachers, leaders, and professionals is a significant hurdle (Ho & Pang, 2023; Lee & Lee, 2022; Suhirman & Prayogi, 2023). Many schools rely on staff trained in individual disciplines, who often default to traditional methods despite receiving training. This underscores the urgent need to not only recruit more dedicated STEM educators but also to equip them with the pedagogical skills necessary for creating truly engaging and interdisciplinary learning experiences.

Recent literature consistently points to continuous professional development for teacher educators as a crucial solution to STEM challenges (English, 2016; Lee & Lee, 2022; Suhirman & Prayogi; 2023). This training must equip them to implement various levels of disciplinary integration where all STEM subjects are equitably represented. These levels are applied hierarchically, starting with the disciplinary level, where subjects are taught distinctly (Leung, 2020; Vasquez, Sneider, & Comer, 2013). The next step, the multidisciplinary level, keeps learning separate but united under a common theme. The interdisciplinary level introduces a deeper connection, linking concepts from two or more disciplines for profound understanding. The pinnacle is the transdisciplinary level, where knowledge from multiple disciplines is applied to solve real-world problems, making the learning experience relevant and impactful.

The core objective of STEM education was to champion a trans-disciplinary approach. This framework effectively equips students from kindergarten through higher education with the skills the global labor market demands. It compels educators to use problem-based, project-based, inquiry-based, and creative learning environments. As noted by Lee and Lee (2022), STEM bridges the gap between theoretical classroom knowledge and real-world application. Consequently, underdeveloped and developing nations urgently need to pursue advancements in education quality and sustainable development through

STEM. They can achieve this by adapting the successful STEM policies and practices of competitive, developed countries with proven economic and cultural success.

STEM Education Disparity, Pedagogical Deficiencies, and Equity Challenges in African and Asian contexts

STEM is a significant postmodern reform, profoundly impacting education and life. It is an integrated theoretical approach for all communities globally (Johnson et al., 2020; Johnson et al., 2021). Its core objective is to transform lifestyles and foster a skilled workforce for the global labor market. However, research shows a disparity in STEM policy and practice, with less effort in Asian and developing countries. A critique paper is thus essential. It should urge developing nations to assess their performance and encourage developed nations to intensify investment. Examining practices in less experienced African and Asian countries is also beneficial.

The COVID-19 pandemic provided a unique chance for narrative analysis in Indonesia (Putra & Narulita, 2023). This study revealed a persistent issue that Asian teachers' pedagogical content knowledge (PCK) is inadequate for integrating STEM. This deficiency, a global problem, confines educators to a mono-disciplinary approach. Teachers struggled during the pandemic because their training focused on subjects in isolation. This mono-disciplinary model fails to support the essential learner-centered approaches such as problem-based, project-based, and inquiry-based learning. Integrated teaching models are crucial for developing the skilled workforce needed for the global labor market.

Like previous research, Putra and Narulita (2023) and other studies investigated STEM education in Indonesia (Wahano, Hariyadi, & Subianthoro, 2022). Their work showed that customized online training can close professional knowledge gaps, enhancing teacher development and STEM quality. This aligns with findings that emerging technologies like artificial intelligence (AI) and virtual reality (VR) positively impact STEM teaching (Chiu & Li, 2023). Beyond pedagogy, a persistent global challenge is undergraduates' difficulty in choosing STEM careers. In Nigeria, this leads to a shortage of practitioners (Badmus & Jita, 2023). Their research found that career outcome expectancy significantly impacts students' decisions to pursue STEM.

Suhirman and Prayogi (2023) reviewed literatures on STEM education challenges. Their goal was to highlight effective pedagogies for teachers in Indonesia and other developed countries. They emphasize the scientific community must disseminate these strategies. The need for pedagogical improvement is widespread. Most Malaysian preschool teachers lack the competency for integrated STEM education (Ho & Pang, 2023). This mirrors a global issue, even in developed countries like the USA (Kelley & Knowles, 2016). The core problem is that teachers at all levels struggle to integrate the diverse philosophies needed foe interdisciplinary STEM. Their traditional mono-disciplinary training hinders this effort. Therefore, countries must significantly expand pre-service and in-service teacher education programs worldwide. Continuous professional development is vital to cultivate specialized STEM educators.

Miao (2023) analysed education policies and practices in the USA and China, specifically within higher education. The core objective is to cultivate a robust STEM education ecosystem. The United States has made progress but still faces significant limitations. Low participation plagues certain demographic groups, including female students, minority students, and those from lower socio-economic backgrounds (Costello, Salehi, Ballen, & Burkholder, 2023). Disparities in gender, race, and parental education level contribute to unequal graduation rates (Blom & Strachan, 2025). This challenge is global. Ethiopia also struggles with low female representation in STEM (Melak & Singh, 2021).

While the USA faces demographic challenges Miao (2023), China actively expands its STEM higher education. However, its heavy reliance on imported USA models creates a contextual mismatch. This policy misalignment impedes desired outcomes and fosters dependency. Globalization and neoliberalism compound these global STEM challenges (Carter, 2017; Miao, 2023). Crucially, Dong, Wang, Yang, and Kurup (2020) teacher knowledge and beliefs are vital for effective STEM implementation. Teacher with strong STEM pedagogy face fewer hurdles. This highlights the on-going need for robust, contextually relevant professional development. External models can otherwise hinder effective STEM integration.

Philosophical Underpinnings and Pedagogical Imperatives of Integrated Approach

The STEM integration approach originated in the USA around the 1900s (Chesky & Wolfmeyer, 2015). It revolutionized education by merging four distinct disciplines: science, technology, engineering, and mathematics. Each discipline has its own unique foundational concepts (ontology), values (axiology), and methodologies (epistemology). Despite their differences, they share many interconnected concepts. This integrated approach diverges sharply from traditional, siloed practices. Its core objective is to foster deep attitudinal and personality change in students and society for the digital age. STEM literacy empowers individuals to improve lifestyles, enhance environmental stewardship, ensure food security, drive economic growth, and address global climate change and security (Mpofu, 2020).

Elevating STEM education requires grasping its core essence and philosophical assumptions. This understanding empowers everyone to recognize and apply the benefits of STEM literacy. STEM's unique essence is twofold: it is forged through integration yet retains the individual nature of its disciplines. This complexity means stakeholders, especially teachers, must grapple with its multifaceted nature. The term STEM remains ambiguous for many educators (Chesky & Wolfmeyer, 2015). This ambiguity arose because integration theory initially only described the disciplines' interconnectedness (Dillon & Wong, 2025). However, the philosophical foundation of the reform promotes the profound significance of STEM within the real-life context of society and education (Chesky & Wolfmeyer, 2015; Shanahan, Carol-Ann Burke, & Francis, 2016).

A summary of the key strengths and weakness associated with the diverse STEM education policies and practices implemented in developed nations is provided in Table 1 (Dillon & Wong, 2025; Lee & Lee, 2022; Moemeke, 2026).

Table 1: STEM Education Policies and Practices in Developed Countries

	Policies and Practices	
Country	Strengths	Weaknesses
USA	• The education system operates by state-level standards. • Students' participation and promising improvement are evident in Trends in International Mathematics and Science Study (TIMSS)	• The education system operates by state-level standards. • The education system lacks a national curriculum. • Higher education receives a low emphasis. • There is a persistent

	and Program for International Student Assessment (PISA) in math and science assessment contests. • It strongly values public education. • STEM occupations are characterized by high demand and higher wages. • A moderate connection exists between high schools and higher education. • Teacher education is evolving with a growing focus on STEM. • The government invests heavily in STEM education. • The government bridges educational pathways between STEM education and industry. Gender-based achievement gaps are comparatively smaller.	shortage of both graduates and teachers who hold advanced degree. • A balanced approach to assessing all STEM components remains not established. • Many STEM programs are subject-specific. • Teachers without formal degrees are prevalent in schools with high minority and poverty enrollments. • Less-experienced teachers are common in schools with high minority and poverty enrollments. • The widespread use of learning technologies (e.g., e-learning, AI) is not yet established. Achievement gaps persist based on socio-economic status (SES) and race/ethnicity.
United Arab Emirates (UAE)	• Significant educational reforms have been made, including the adoption and integration of Common Core Curriculum Standards (CCSS) in K-12 private schools to replace isolated curricula. • The government launched a broad reform agenda to boost national performance in international assessments like TIMSS and PISA, aiming for a top global ranking. • To attain its reform agenda,	• A persistent lack of awareness and student interest exists in STEM fields. • Students show a weak desire for jobs in STEM fields. • Students often prefer careers in the police or armed forces. • The student participation rate in tertiary education is low. • There is a shortage of talented workers. • A weak working culture

	the government has implemented innovative learning strategies like project-based, design-based, and inquiry-based. • The government has also embraced technologies such as AI in the classroom. • There is a strong interest in funding through both federal and non-government initiatives. • An "innovation hub" was recently launched to increase informal education.	supports continuous learning. • A formal linkage between schools and higher institutions is not yet clearly established. • There is no official data on gender, SES, and ethnicity differences. • Despite a lack of official data, disparities are supposed to exist across gender, SES, and ethnicity. .
Taiwan	• STEM education is integrated into general curriculum guidelines and local bureau policies for K-12 students. • Students performed averagely on PISA and TIMSS international assessment contests. • The government is heavily invested in digital transformation. • The government has leveraged technologies like AI, mobile devices, and robots. • The government has established centers for technology education. • Professional development training is offered to teachers and leaders. • A government-driven desire for substantial investment and funding is evident. • STEM is delivered via formal schooling and non-	• The education system lacks a national curriculum. • A shortage of educators and a lack of specific STEM education goals and practices for K-12 persist. • Teachers feel less confident in their abilities. • Teacher education programs often focus on single disciplines. • The lack of trained teachers extends into higher education. • STEM fields faced challenges like a declining student-to-teacher ratio, inequality (gender, SES, race), and low female students participation. • There is a scarcity of STEM professionals.

	formal avenues (e.g., camps and competitions). • The nation has a high demand for STEM professionals.	
Sweden	• National and international assessments (PISA, TIMSS) in math and science are conducted. • The nation has been a top scorer in international math and science contests. • Teachers must hold a teaching certificate from a teacher education program. • Technology is heavily used for learning in both formal and non-formal schooling. • Higher education institutions have taken initiatives to balance technology in testing and assessment. • The nation continues to invest in research. • Education is delivered through formal schooling and non-formal settings like museums, summer camps, and workshops. • Interestingly, there is no gender difference in performance, with females outperforming males in compulsory school education. • Graduates from vocational programs are highly employable. • Graduates from higher education preparatory programs have a good employment rate.	• There is no national curriculum and a reform agenda item. • The country faces challenges including scarce time allocation, lack of qualified teachers, and low attention to preparing technology teachers. • The technology subject itself remains ambiguous. • Technology is not balanced as a STEM component in testing and assessment. • Females are underrepresented in upper secondary and higher education.

Singapore	• The education system follows a government-supported national curriculum. • A mono-disciplinary approach has long benefitted K-12 schooling. • A mono-disciplinary approach has contributed to students' high PISA scores. • Educators and policymakers have discussed STEM integration. • STEM has historically been offered in a limited capacity in special schools. • STEM was considered an 'A' level course in post-secondary education. • The government is eager to invest substantial funding to address the shortage of qualified graduates, low teacher readiness, and scarce curriculum time. • The country uses non-formal avenues like robotics and science clubs to develop students holistically beyond the formal curriculum. • There is a high demand for related jobs.	• The education system follows a government-supported national curriculum. • STEM offering in special schools was in a limited capacity. • STEM is often perceived by the public as non-examinable. • Widespread STEM adoption faces challenges including a lack of specialized teachers training (leading to a shortage of qualified graduates and low teacher readiness) and scarce time allocation for the curriculum. • A modest linkage between schools and higher education with a traditional, rigid structure complicates efforts. • The country faces challenges including low female participation and a general lack of interest in STEM careers.
Ireland	• The general approach emphasizes an integrated learning model, supported by government policy from primary schools to higher education. • Impressive and stable results were recorded in international assessments like TIMSS and PISA. • There is a moderate linkage between different educational levels. • The education system is	• The nation lacks a single curriculum. • There is a lack of integrated assessment strategies to balance various STEM components in learning. • Gender stereotypes still exist. • The country faces challenges like ignoring STEM teachers and a drop in students' continuing education from primary school to higher levels.

	boosted by heavy technology use, strong incentives, and funding from the government and stakeholders. • Formal and non-formal educations are connected through summer camps and competitions. • The education system is relatively fair with no major gender differences in results. • There is a high demand for skilled workers and a growing need for specialized experts.	
Hong Kong	• The education system has a partial curriculum framework that is always changing due to new policies. • STEM education is promoted as a big change in education, not just a single subject. • STEM education for primary and secondary students follows the motto "STEM FOR ALL." • STEM education is shaped by stakeholders' research and measured in school and social settings. • The country still struggles with hands-on learning. • The government plays a big role in policy design, giving lots of money and resources, and working hard to close the talent gap. • Learning relies heavily on technology. • Non-formal from diverse groups like non-government organizations (NGO's) and companies uses competitions, workshops, and field trips to play a key role.	• The education system lacks a national curriculum. • Low teacher and school readiness often stop the curriculum from being used well. • PISA achievement scores show a decreasing trend. • There is a small connection between schools and higher education. • The country still struggles with too few teacher training programs, and a lack of balanced ways to assess all parts of STEM. • Even with limited data, differences based on gender, wealth, and race likely exist. • The nation faces a high demand for skilled workers.

Germany	• The 16 states and "Standing Conference" manage the very different education system at the national level. • STEM gets a lot of attention. • The education system heavily uses digitalization. • There is a strong link between formal school education and non-formal company training programs, called dual vocational training. • There is a very low unemployment rate of 3% among those with vocational qualifications. • A strong connection exists between formal, non-formal, and informal education through many institutions and spaces. • The Federal Ministry of Education is very interested in supporting STEM programs, including getting women more involved. • A moderate link between schools and higher education remains.	• The Federal Ministry of Education is not in charge of making comparable school rules or curricula. • Vocational programs are focused on to produce most skilled workers for jobs. • The education system faces challenges with unsatisfactory PISA and average TIMSS scores, and a shortage of skilled workers in the labor market. • Technology education is a separate subject, and an integrative approach is not common in schools. • The regular education system lacks technology education and specific rules for technology, engineering, or informatics. • Teachers lack the ability to integrate subjects. • There are no focused teacher education programs for technology. • A balanced way to assess all parts of STEM (MINT) is not yet in place.
Finland	• The education system uses a National Core Curriculum that focuses on skills, learning through real-world topics, broad abilities, and science/engineering careers, especially in middle school. • The country consistently achieves high scores in international assessments like PISA and TIMSS. • The government has	• The education system lacks a national curriculum. • The curriculum and teacher education generally use a single-subject approach. • There is a low student motivation in math and science, causing low enrollment. • There is a shortage of skilled workers in a quickly changing technology world.

	invested heavily in STEM education through national development projects. • The education system connects formal and non-formal learning through initiatives like entrepreneurial education, competitions, and museums. • Teachers struggle to work together across different subjects. • The education system heavily uses technology and has been the subject of many studies.	• There is a modest link between schools and higher education. • The difference in STEM performance between boys and girls is not significant. • There is a difficulty to fairly assess all parts of the STEM curriculum.
Canada	• The education system uses a mix of old and new ways. • The "Educate to Innovate" policy focuses on math and science to change the economy and culture. • Primary schools use an integrated approach. • Teachers are more skillful at designing complex units in primary schools. • The federal government gives money to non-profit groups, private companies, and professional societies to support STEM education. • There is a high demand of skilled workers.	• The education system lacks a national curriculum. • Engineering and technology are often left out of K-12 schools and plan. • The education system relies heavily on a single-subject approach. • Secondary schools and teacher education programs pay little attention to a single-subject approach. • There is a noticeable lack of teachers for secondary schools. • There is a modest link between schools and higher education. • There are no national assessment strategies to balance all parts of STEM. • The federal government does not give specific money to fairly test all parts of STEM. • It is estimated that half of post-secondary students are

		international or immigrant. • Though data is limited, differences based on gender, SES, or race still exist.

THEMATIC ANALYSIS

The thematic analysis of developed nations' policies and practices for STEM education reveals key strengths and weaknesses across several academic areas. The investigation was conducted around the following central themes: curriculum, pedagogics, schools and higher institutions linkage, formal, informal, and non-formal education and industry linkage, professional development training, assessment, technology utilization, equity and inclusion based on gender, SES, and race/ethnicity differences, employment opportunities, and government investment.

Thematic Analysis 1: Curriculum

All of the developed nations referenced in this study except Singapore lack an independent national curriculum framework for STEM education. At all education institutions, STEM is offered within the established general curriculum. Some countries, like the USA, use state-level curricula for STEM, whereas the UAE applies the CCSS framework, especially for k-12 private schools.

Thematic Analysis 2: Pedagogics

The majority of developed nations deliver STEM education using the established mono-disciplinary approach. For instance, students from Singapore's K-12 schools have benefited from this approach for a considerable period. In contrast, UAE employs student-centered methods, like project-based learning. Similarly, Ireland is concentrating its efforts on implementing an integrated approach to instruction. Likewise, Hong Kong is striving to adopt student-centered, hands-on learning methodologies.

Thematic Analysis 3: Schools and Higher Institutions Linkage

Some developed nations are actively attempting to moderately coordinate between schools and higher education institutions. Conversely, other nations are executing this coordination at a much lower level. Certain countries, such as the UAE, are reportedly making no attempts at such institutional linkage. Specifically, the USA has given minimal attention to this coordination among higher education institutions.

Thematic Analysis 4: Formal, Informal, and Non-formal Education and Industry Linkage

The USA is unique as the only government that established the coordination between formal STEM education and industry. The UAE has focused its efforts on integrating formal and informal education through the concept of an ‘innovation hub’. Taiwan, Sweden, Singapore, Ireland, Hong Kong, and Finland deliver STEM education by linking formal and non-formal education using platforms such as camps and competitions. Germany stands out from the aforementioned examples by fostering a robust connection among formal-, informal-, and non-formal education. Conversely, available data regarding Canada’s attempts to integrate these four educational modalities is recognized as limited.

Thematic Analysis 5: Professional Development Training

Professional development training efforts in the majority of developed nations have not yielded encouraging results in producing the skilled human capital required for the 21st century, specifically teachers, educators, and workers. In this regard the superior endeavor demonstrated by Taiwan and Hong Kong is noteworthy. Nevertheless, a deficit of skilled professionals, inadequate numbers of graduates, and a lack of teacher preparedness are manifest not only in developed countries but also present a significant challenge at the global level.

Thematic Analysis 6: Assessment

Both developed nations and the global community at large have not yet to implement assessment strategies that equitably address all four components of STEM. Observations from international assessments such as PISA and TIMSS indicate that while some countries achieve average performance levels, others scored low results. Notably, countries like Finland, Sweden, Singapore, and Ireland have cultivated a consistent practice of attaining high assessment scores.

Thematic Analysis 7: Technology Utilization

In most developed nations, technology is extensively applied to both STEM education and broader educational practices. Contrary to expectations, however, countries such as the USA are observed to utilize this technology to a comparatively limited extent.

Thematic Analysis 8: Equity and Inclusion Based on Gender, SES, and Race/Ethnicity Differences

Despite evidence limitations, the progress made towards equitably addressing the disparities among students based on gender, SES, and race/ethnicity remains exceedingly limited in over half of developed countries. Furthermore, female participation is notably low in nations such as Taiwan and Singapore, particularly evident in upper secondary schools and higher education institutions in Sweden. Conversely, the Federal Ministry of Education in Germany has demonstrated significant commitment to increasing female involvement. While the finding that gender stereotypes still exist in Ireland, the performance gaps attributed to gender differences are narrow across USA, Finland, Sweden, and Ireland. In fact, in Sweden, female performance surpasses that of males.

Thematic Analysis 9: Employment Opportunities

Across all developed nations, there is a strong imperative to facilitate employment opportunities and offer competitive compensation for young graduates who are skilled professionals in STEM. In Sweden and Germany, graduates of vocational programs exhibit high employability. Similarly, graduates of higher education preparatory programs in Sweden also possess high employment prospects. In Germany, the unemployment rate for individuals with vocational qualifications is exceptionally low, registering as low as 3%. Nevertheless, the general readiness demonstrated by young people for these careers is significantly limited. Furthermore, in the UAE, student interest in STEM careers is notably weak. Instead, they demonstrate a preference for entering professions such as the police and the armed forces.

Thematic Analysis 10: Government Investment

All developed nations exhibit a strong propensity and commitment to making substantial investments in STEM education, research, and development, and other related initiatives.

DISCUSSION

Despite the global recognition of STEM's importance, a significant weakness lies in the absence of comprehensive national STEM curricula, even in highly developed countries like the USA. This fragmentation leads to STEM education being primarily integrated into existing conventional subject curricula. This hinders a truly interdisciplinary approach. Consequently, both teachers and students often adopt a mono-disciplinary approach. That makes challenging to cultivate a well-rounded workforce equipped with the holistic knowledge, skills, and attitudes demanded by the modern global labor market. Furthermore, in many nations, STEM education is not treated as an independent subject, with minimal allocated teaching time. Countries like Germany and Hong Kong even categorize it as a co-curricular activity, underscoring a need for greater prioritization and dedicated focus.

Despite the aforementioned challenges, research consistently indicates that STEM education policies and reform agendas are global priorities. The international community largely believes in STEM's capacity to derive economic, cultural, social, and political transformation. This is evident in efforts to leverage STEM for addressing critical issues such as environmental protection, food security, climate change, and global security. However, a significant global hurdle remains the severe shortage of qualified STEM educators, leaders, and professionals. This scarcity is largely due to insufficient prioritization and investment in teacher education programs specifically for STEM. It profoundly impacts the development of STEM education and the global workforce supply.

On a positive note, most research findings show that countries worldwide are effectively leveraging technology to enhance the teaching and learning of STEM, demonstrating commendable dedication and effort. While significant success has been achieved in K-12 STEM education, the emphasis on STEM in higher education institutions remains relatively low. Efforts to bridge the gap between schools and higher education through STEM initiatives have been moderate. It is crucial to acknowledge that establishing robust connections between these educational levels and offering high-quality, comprehensive STEM education in higher education are vital areas requiring immediate attention globally. Another critical area needing improvement is the balance of STEM components in assessment strategies. A common practice, exemplified by assessments like PISA and TIMSS, often disproportionately focuses on science and mathematics, neglecting the engineering and technology aspects.

Governments in many countries are commendably allocating substantial investment and grant funding to accelerate the growth of STEM education, recognizing its importance for future development. Their efforts to link formal and non-formal education with industry are also noteworthy. However, with only a few exceptions, there has been limited progress in effectively connecting formal and informal education Dillon and Wong (2025), as well as formal education and industry. This area presents a significant opportunity for future development. Furthermore, research consistently reveals persistent disparities in STEM education based on gender, SES, and race across various countries. Despite individual national efforts, more proactive and diligent work is imperative to address these inequalities. For instance, given that women comprise approximately half of the global population, increasing their participation in STEM fields is crucial. It is not only for achieving equity but also for meeting the escalating demand for STEM professionals worldwide.

In line with the first research question derived from the study's objective, the strengths and weaknesses of STEM education policies and practices in developed nations were identified. The rational for this undertaking is to enable developing countries, generally global communities to enhance their knowledge, awareness, and comprehension. Thus, this allows them to advance STEM education within their own unique cultural, economic and political contexts and thereby influence globalization.

In line with the second research question, current STEM education policies and practices in developed nations only partially address global demands. These nations pioneered and invested heavily in STEM to enhance economic competitiveness. But, many still lag in developing knowledge-based economies compared to their peers, due to a failure to fully close the gap between policy goals and implementation. A persistent global shortage of qualified teachers and professionals highlights the core ineffectiveness. This underscores that current approaches do not yet produce the required volume of skilled talent.

In line with the third research question, an analysis of successful national-level STEM initiatives informs strategic policy adaptation by providing proven models, policies, and practices for curriculum design, professional development, and interdisciplinary integration. It highlights how countries effectively align educational goals with economic needs, demonstrating how policies can be contextualized to fit unique cultural, historical, and economic settings. Therefore, this enhances both STEM knowledge and public awareness in other global contexts.

CONCLUSION

While developed nations have undeniably gained significant benefits from STEM education, the journey is far from over, even for pioneers like the USA. A substantial investment in multifaceted inputs is crucial for enhancing STEM education and employment, presenting a considerable challenge for both developed and developing countries. This ongoing need for resources, coupled with the inherent complexity of STEM learning processes that demand high levels of attention, highlights the continuous effort required to foster a robust STEM ecosystem. The global landscape necessitates this persistent dedication to ensure nations can effectively navigate the demands of the 21st century.

Ultimately, STEM education exceeds a mere academic concept. It is a vital mindset that must be diligently woven into the fabric of daily life, both individually and nationally. The integration of scientific thinking, technological prowess, engineering principles, and mathematical reasoning is fundamental for innovation and progress. The remarkable advancements in fields like AI and robotics, serving as prime examples of STEM's tangible benefits. They play a critical role in global community development and national advancement. Embracing this mindset is not just an option, but a global imperative for achieving sustainable development and securing a prosperous future for all.

IMPLICATIONS AND RECOMMENDATIONS

The discussion on STEM education underscores its critical role as a global imperative for national advancement and sustainable development, necessitating a dedicated and comprehensive approach. To fully realize this potential, it is essential to design and implement an independent curriculum, policy, strategy, and practice specifically for STEM education. This requires immediate action, urging countries worldwide to recognize STEM education as a core, full-time subject. Furthermore, addressing the severe shortage of qualified STEM educators, leaders, and professionals is paramount, which can be achieved through expanding both pre-service and in-service teacher education programs. A seamless transition and enhanced performance in STEM fields from K-12 to higher education can be fostered by strengthening the interconnections between schools and higher education institutions.

A balanced emphasis across all disciplines within STEM is crucial for effective implementation. Moreover, to ensure the success of STEM education and subsequent employment, it is vital to foster cohesion between formal-, non-formal-, and informal education, and industry. This integrated approach will facilitate the deployment of qualitatively and effectively prepared graduates into the workforce, enabling them to make a positive impact on community life. Addressing disparities caused by gender, race, and socioeconomic differences is also strongly advocated by research, highlighting the need for inclusive STEM initiatives. Ultimately, for all nations, particularly underdeveloped and developing countries, prioritizing quality STEM education is not merely an option but a matter of survival, ensuring sustainable development and national advancement.

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