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ORIGINAL ARTICLE

Vietnam's STEM Education Landscape: Evolution, Challenges, and Policy Interventions

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ABSTRACT
In Vietnam, national policies increasingly prioritize STEM education, recognizing its critical role in developing future workforce skills. However, significant gaps remain between policy and practice. Currently, STEM education in Vietnam is primarily found in extracurricular activities, with limited systematic integration into the formal curriculum. Key challenges include inadequate teacher competence, insufficient resources, sociocultural bias, and difficulties in translating national STEM goals into classroom practices. Future research should focus on several key areas to further strengthen STEM education in Vietnam. Evaluating effective curriculum models will help integrate STEM into the core curriculum more systematically. Assessing professional development programs will ensure that teacher training initiatives are effective and impactful. Addressing sociocultural bias is necessary to promote diversity and inclusion in STEM fields. Analyzing regional collaboration networks can identify best practices and foster knowledge sharing among ASEAN countries. Implementing context-specific reforms will ensure that solutions are tailored to the unique challenges and opportunities in Vietnam. Addressing these priorities will enable Vietnam to make informed decisions, strengthen STEM education, and develop a skilled workforce for sustainable economic growth.

1. INTRODUCTION

STEM education in Vietnam began in 2015 and has since evolved significantly, driven by policy directives and collaborative efforts (Thi To Khuyen et al., 2020). These policies have integrated STEM into the national curriculum and educational priorities, while extracurricular activities such as hands-on experiences, competitions, and projects have bolstered student interest and proficiency. Public-private partnerships have been instrumental in advancing STEM education, bringing resources, expertise, and innovative approaches to the forefront. These collaborations have modernized STEM infrastructure, developed relevant curricula, and provided mentorship and internship opportunities. Vietnam's educational reform efforts have focused on integrating STEM principles across all levels of education (Nguyen et al., 2020). At the primary school level, hands-on learning and interdisciplinary approaches are used to cultivate critical thinking and creativity. Secondary education emphasizes project-based learning, experimentation, and collaboration to deepen scientific exploration. Tertiary institutions incorporate specialized STEM programs, research opportunities, and industry partnerships to prepare students for STEM careers (Tuong et al., 2023). In primary education, the focus is on introducing young students to STEM concepts through interactive and engaging activities that stimulate curiosity and foundational understanding. These activities are designed to develop problem-solving skills and encourage a love for learning science and technology. In secondary education,

the emphasis shifts to more structured project-based learning where students engage in experiments and collaborative projects that require the application of scientific methods and engineering principles. This approach not only deepens their understanding of STEM subjects but also hones their teamwork and communication skills. Tertiary institutions in Vietnam have integrated specialized STEM programs that offer students opportunities for advanced study and research. Partnerships with industry provide practical experience through internships and collaborative projects, ensuring that students are well-prepared for STEM careers. These programs are designed to align academic learning with the skills demanded by the modern workforce, fostering innovation and adaptability. By embedding STEM education throughout its educational framework, Vietnam aims to create a workforce that is innovative, adaptable, and equipped to tackle complex challenges in a technology-driven world (Le & Bui, 2021; Tuong et al., 2023). The comprehensive integration of STEM at all educational levels ensures that students develop a strong foundation in STEM disciplines, preparing them for future technological advancements and contributing to the country's economic growth and development.

Recognizing disparities in STEM participation across geographic regions, genders, and demographic groups in Vietnam has led to targeted policies and programs to address these inequities (Nguyen & Ha, 2023; Zhan et al., 2023). Urban areas typically benefit from better-resourced schools, qualified teachers, and a greater number of extracurricular STEM activities compared to rural regions. To bridge this gap, Vietnam has implemented several initiatives, including mobile STEM education units that bring resources directly to underserved areas, distance learning initiatives that leverage technology to provide STEM education remotely, and significant investments in rural school infrastructure to enhance the learning environment (Ho et al., 2020). Women have historically been underrepresented in STEM fields. To promote gender equity, Vietnam has introduced various initiatives aimed at encouraging more girls to pursue STEM education and careers. These initiatives include mentoring programs that pair girls with female STEM professionals, tailored STEM outreach activities designed to engage and inspire young women, and efforts to challenge and change gender stereotypes within STEM disciplines. These strategies aim to create a more inclusive and supportive environment for women in STEM (Ho et al., 2020). Ethnic minorities and socioeconomically disadvantaged populations also face significant barriers to accessing quality STEM education. To address these disparities, Vietnam has implemented inclusive policies and programs such as targeted scholarships that provide financial support to students from disadvantaged backgrounds, community-based STEM initiatives that involve local communities in promoting STEM education, and culturally sensitive teaching methods that respect and incorporate students' cultural backgrounds into the learning process. These measures are designed to ensure that all students, regardless of their demographic background, have equitable access to STEM education and opportunities to succeed in these fields. By addressing geographic, gender, and demographic disparities through these customized policies and programs, Vietnam aims to provide all students with equal opportunities to pursue and succeed in STEM fields. These efforts are critical for fostering a diverse and inclusive STEM workforce that can drive innovation and economic growth. Ensuring that every student has access to quality STEM education not only supports individual achievement but also contributes to the broader goal of national development and competitiveness in the global economy (Yamada, 2023).

Comparative analyses between Vietnam's STEM education initiatives and those of its regional peers provide valuable insights into strengths, challenges, and potential areas for improvement. Vietnam's efforts demonstrate significant strengths in government support, policy implementation, investment in infrastructure, and teacher training. The emphasis on public-private partnerships and extracurricular STEM programs also distinguishes Vietnam from some regional peers. However, challenges persist, including disparities in access to STEM education, outdated teaching methods, inadequate resources, and misalignment with industry needs. Fostering innovation and entrepreneurial skills among students remains an ongoing challenge. These analyses highlight areas for enhancement, such as improving teacher training, promoting gender and socioeconomic equity in STEM participation, updating curricula to emphasize hands-on and experiential learning, and strengthening collaborations between academia, industry, and government. By learning from effective strategies in neighboring countries, Vietnam can enhance its STEM education ecosystem. Overall, these comparative analyses offer Vietnam the opportunity to build on its strengths, address its challenges, and continuously improve its STEM education initiatives, thereby developing a skilled workforce capable of driving innovation and sustaining economic growth in a competitive global landscape (Pham, 2023).

2. LITERATURE REVIEW

Since its emergence in the early 1990s, STEM education, which integrates science, technology, engineering, and mathematics, has garnered substantial attention as an interdisciplinary approach (Baran et al., 2016; Martín-Páez et al., 2019; Struyf et al., 2019). Acknowledged for its capacity to bridge disciplinary boundaries and equip students with the skills necessary to address contemporary global challenges such as digital transformation and the requirements of the knowledge economy, STEM fosters critical thinking and problem-solving skills, essential in today's technology-driven society (English, 2016; Schweingruber et al., 2014). Pedagogies that integrate STEM disciplines hold considerable promise in enhancing student motivation and participation in STEM fields of study and future careers (Bryan et al., 2015; Kendricks et al., 2019). These integrated approaches encourage students to see the connections between different disciplines, making learning more relevant and engaging. By involving students in hands-on projects and real-world problem-solving activities, STEM education can significantly boost their interest and retention in these critical fields. Although recognized as essential for fostering global citizenship and advancing economies, the implementation of STEM education varies across the world. Many regions face challenges related to the quality and equitable access to STEM education (Al Salami et al., 2017; Margot & Kettler, 2019; Gül et al., 2023). These challenges include disparities in resource allocation, differences in teacher preparedness, and varying levels of support from educational policies. In many areas, especially in underserved or rural regions, students often lack access to well-equipped laboratories, up-to-date educational technologies, and experienced STEM educators. This lack of resources can hinder their ability to engage fully in STEM learning and develop the necessary skills for future careers. Moreover, socioeconomic factors can exacerbate these disparities, leading to unequal educational opportunities and outcomes. There is a pressing imperative for research aimed at devising best practices tailored to diverse educational settings. This research study should focus on identifying effective teaching strategies, curriculum models, and policy frameworks that can enhance the quality and accessibility of STEM education. By understanding the unique challenges and opportunities within different contexts, educators and policymakers can develop targeted interventions that promote inclusive and high-quality STEM education for all students. Addressing these issues requires a collaborative effort among governments, educational institutions, and the private sector. Investments in teacher training, infrastructure, and educational resources are critical. Additionally, fostering a culture that values and supports STEM education can help ensure that all students have the opportunity to succeed in these fields, ultimately contributing to a more innovative and economically prosperous society.

STEM education in Vietnam was inaugurated in the mid-1980s under the auspices of the Ministry of Education and Training (MOET). Initially, its primary focus was on preparing students for international science competitions and nurturing scientific inquiry. This endeavor was geared towards fostering sustainable development, modernizing education, and bolstering high-tech trade to break free from the middle-income trap. Vietnam's commitment to this cause was highlighted by its participation in International Science Olympiads in 2015, showcasing the country's ambition to cultivate a generation of scientifically proficient students. Despite Vietnam's rich cultural heritage in science and technology, its STEM education sector has not yet matched that of its regional counterparts. Several factors contribute to this lag, including underinvestment in educational infrastructure and resources, a reliance on outdated teaching methods, and significant disparities in access to quality STEM education between urban and rural areas. Urban schools tend to have better facilities, more qualified teachers, and greater access to extracurricular STEM activities compared to their rural counterparts. The underinvestment issue is particularly critical. Many schools lack the modern laboratories and technological tools necessary for effective STEM education. Without these resources, teachers and students are limited in their ability to engage in hands-on, experiential learning that is essential for understanding complex STEM concepts. Moreover, traditional teaching methods that emphasize rote memorization over critical thinking and problem-solving are still prevalent. These methods do not align well with the dynamic and integrative nature of STEM education, which requires an approach that encourages exploration, creativity, and practical application of knowledge. Disparities in access to STEM education also pose a significant challenge. Students in rural areas often do not have the same opportunities as those in urban centers, leading to unequal educational outcomes. This gap perpetuates a cycle of limited career opportunities and economic disparity for students from less advantaged backgrounds. To address these issues, Vietnam needs to increase its investment in educational infrastructure and resources, adopt modern teaching methodologies that promote active learning, and implement policies that ensure equitable access to STEM education across all regions (Chen et al., 2021). By focusing on these areas, Vietnam can develop a robust STEM education system that not only prepares students for

international competitions but also equips them with the skills and knowledge to thrive in a technology-driven global economy.

Vietnam's strategic response to the challenges posed by the Fourth Industrial Revolution includes substantial investments in STEM education, aligning with its developmental aspirations for 2035 and 2045. These initiatives aim to enhance STEM accessibility, improve teacher training, upgrade facilities, and align skill sets with the evolving demands of the labor market nationwide. During the 2010s, there was a notable surge in extracurricular STEM programs, with private centers importing curricula and public-private partnerships embracing global best practices (Phuong et al., 2023; Vu et al., 2019). These programs have provided students with additional opportunities to engage in STEM learning outside of the traditional classroom environment, fostering interest and proficiency in STEM disciplines. Despite these efforts, there remains a pressing need for more robust incentives to recruit and retain teachers, particularly in underserved regions. While universities have introduced specialized STEM educator training programs, the recruitment and retention of qualified teachers continue to be significant challenges. To address this, it is essential to offer competitive salaries, career development opportunities, and other incentives to attract and retain skilled educators in STEM fields. MOET has been progressively increasing its investment in STEM teacher development and formulating technology education policies. These actions underscore the growing recognition of STEM's crucial role in preparing students for a STEM-driven economy. MOET's initiatives include comprehensive professional development programs for teachers, integrating modern teaching methodologies, and providing access to the latest educational technologies. Furthermore, the alignment of STEM education with labor market demands is critical. By ensuring that the skills taught in schools are relevant to the needs of the industry, Vietnam can create a workforce that is well-prepared for the technological advancements of the future. This involves continuous collaboration with industry stakeholders to update curricula, incorporate real-world applications, and provide students with practical experiences through internships and industry projects (Chen et al., 2021). In summary, Vietnam's strategic investments in STEM education are essential for addressing the challenges of the Fourth Industrial Revolution and achieving the country's long-term developmental goals. By improving accessibility, enhancing teacher training, upgrading facilities, and aligning education with labor market needs, Vietnam can develop a skilled workforce capable of driving innovation and sustaining economic growth. The continued commitment to these initiatives will ensure that Vietnam remains competitive in the global economy and prepares its students for the demands of the future.

This study provides a synthesized analysis of research on the evolution, challenges, and future trajectories of STEM education across all levels of education in Vietnam. It meticulously examines policy frameworks, curricular models, and systemic complexities, offering recommendations tailored to Vietnam's unique STEM education landscape. In addition, the review delves into national policies, teacher training programs, public-private partnerships, and extracurricular activities, critically assessing issues such as access, equity, teacher readiness, curriculum effectiveness, and alignment with workforce demands. Key findings from the analysis highlight several areas needing attention. Policy frameworks in Vietnam have increasingly prioritized STEM education, but there remains a significant gap between policy and implementation. Curricular models often lack coherence and integration, leading to inconsistent educational experiences across different regions and schools. Systemic complexities, such as varying levels of resource availability and socio-economic disparities, further exacerbate these challenges. The review identifies teacher training as a critical area for improvement. Many educators lack the necessary training to effectively teach STEM subjects, resulting in a need for comprehensive professional development programs. Public-private partnerships are also highlighted as a potential avenue for enhancing STEM education, providing additional resources, expertise, and real-world learning opportunities for students. Extracurricular activities have been found to play a significant role in promoting STEM education, yet access to these programs is often uneven. Efforts must be made to ensure that all students, regardless of their background, have equal opportunities to engage in STEM activities. The overarching objective of this study is to present evidence-based strategies aimed at elevating the quality and outcomes of STEM education in Vietnam. Recommendations include integrating STEM subjects more thoroughly into the national curriculum, moving away from rote memorization towards hands-on learning experiences, and investing in modern educational infrastructure. Furthermore, promoting gender equality in STEM fields and fostering collaborations between the government, educational institutions, and the private sector are essential steps towards creating a supportive and inclusive STEM education environment. By addressing these challenges and implementing the proposed strategies, Vietnam can enhance its STEM education

system, develop a skilled workforce, and position itself competitively on the global stage. This comprehensive approach will ensure that STEM education in Vietnam not only meets current demands but also prepares students for future technological advancements and economic growth.

3. MATERIALS AND METHODS

Data was collected from the databases such as Scopus, Web of Science, ERIC, and Education Source. By analyzing and comparing Vietnamese STEM education with that of other countries, several priorities and future prospects for the development of STEM education in Vietnam have been proposed. This comparative analysis revealed both strengths and weaknesses in Vietnam's current STEM education system. The analysis highlighted the need for comprehensive reforms to address significant gaps in teacher training, curriculum development, and resource allocation. For instance, there is a notable shortage of well-trained STEM educators, which impacts the quality of instruction and student engagement. The current curriculum also lacks systematic integration of STEM subjects, often relegating them to extracurricular activities rather than embedding them within the core academic framework (Gale et al., 2020; Geesa et al., 2020). Additionally, inadequate resource allocation has resulted in insufficient access to modern educational technologies and well-equipped laboratories. The analysis identified several successful strategies from other countries that Vietnam can adapt to its own context (Le et al., 2021). One key strategy is the implementation of systematic STEM curricula that integrate science, technology, engineering, and mathematics into the core educational experience of students at all levels. Countries like Singapore and China have demonstrated the effectiveness of such approaches, leading to high student performance and strong workforce preparedness. Increased investment in educational infrastructure is another crucial strategy. This includes developing state-of-the-art laboratories, providing access to modern teaching tools, and ensuring that schools are equipped to deliver hands-on, experiential learning experiences (Tytler et al., 2008). Such investments are essential for fostering a practical understanding of STEM concepts among students. Establishing robust public-private partnerships is also vital. Collaboration between government, educational institutions, and private sector entities can provide additional resources, expertise, and real-world learning opportunities. These partnerships can help bridge the gap between academic learning and industry requirements, ensuring that students are well-prepared for the demands of the modern workforce. By adopting these strategies, Vietnam can enhance its STEM education system, addressing current weaknesses and building on its strengths. Comprehensive reforms, targeted investments, and strategic collaborations will enable Vietnam to develop a skilled workforce, drive innovation, and support sustainable economic growth.

Priorities for the development of STEM education in Vietnam include integrating STEM subjects more thoroughly into the national curriculum and moving away from rote memorization towards more practical and hands-on learning experiences (Le et al., 2021). A more integrated approach would ensure that STEM subjects are not merely optional or extracurricular but are central components of the educational experience from primary through secondary education. This approach fosters critical thinking, creativity, and problem-solving skills, which are essential for the modern workforce. Additionally, there is a pressing need for continuous professional development for educators. Providing teachers with ongoing training opportunities is crucial to ensure they are well-equipped with the latest pedagogical strategies and knowledge in STEM fields. This professional development can include workshops, certification programs, and access to resources that help teachers implement effective STEM teaching practices. Developing necessary infrastructure is also a critical priority. This includes establishing well-equipped laboratories that allow students to engage in experimental and experiential learning. Access to modern educational technologies, such as computers, software, and internet connectivity, is essential to support interactive and technology-driven STEM education. Enhancing these resources will enable schools to provide a learning environment that reflects the technological advancements in STEM fields. By focusing on these priorities-curriculum integration, teacher professional development, and infrastructure enhancement-Vietnam can create a robust STEM education system. This system will prepare students with the skills and knowledge necessary to thrive in a rapidly evolving technological landscape and contribute to the country's economic growth and development.

Future prospects for STEM education in Vietnam involve fostering collaborations between the government, educational institutions, and the private sector to create a supportive ecosystem for STEM education. These collaborations can provide essential resources, expertise, and real-world learning opportunities that align educational outcomes with industry needs. Such partnerships can ensure that the curriculum remains relevant and up-to-date with technological advancements and market demands. Promoting gender equality in STEM fields is another critical

prospect. Addressing socio-cultural biases and encouraging more girls and women to pursue STEM education and careers will help create a more diverse and inclusive workforce. This can be achieved through targeted outreach programs, scholarships, mentorship opportunities, and awareness campaigns that highlight the achievements of women in STEM. Investing in teacher training and capacity building is also crucial for developing a more inclusive and effective STEM education environment. Continuous professional development for educators will ensure they have the skills and confidence to deliver high-quality STEM instruction. This includes providing access to the latest teaching methods, technologies, and resources. By adopting these strategies, Vietnam can build a skilled workforce capable of driving innovation and economic growth. A strong emphasis on STEM education will not only equip students with the necessary competencies to succeed in the 21st-century job market but also position Vietnam competitively on the global stage. Through collaborative efforts, gender equality initiatives, and sustained investment in education, Vietnam can leverage STEM education to foster a culture of innovation and technological advancement, contributing to sustainable development and global competitiveness.

4. RESULTS AND DISCUSSION

4.1. Results

Vietnam's STEM Education in the Context of Other ASEAN Nations

STEM education is crucial for developing human capital and transitioning to knowledge-based economies in the ASEAN region, with varying levels of development among member countries (OECD, 2022). Singapore and Malaysia, as early adopters of STEM education, have implemented comprehensive policies, curriculum reforms, and teacher training initiatives, leading to high international rankings. Conversely, Vietnam, Thailand, and Indonesia have only recently started prioritizing STEM education. Over the past decade, Vietnam has made significant efforts to prioritize STEM in its educational policies. However, there remains a gap between policy aspirations and on-ground implementation. STEM education in Vietnam is often limited to extracurricular activities rather than being fully integrated into the core school curriculum. A World Bank survey reveals that only a quarter of Vietnamese high schools offer STEM education, compared to 60% of the secondary schools (Pham, 2023; Phuong et al., 2023; Suriyabutr & Williams, 2021). This disparity highlights the need for greater efforts to bridge the gap between policy intent and implementation, ensuring that STEM education becomes an integral part of the educational experience for all students in Vietnam. By investing in comprehensive policies, curriculum reforms, and teacher training initiatives, Vietnam can improve the quality and accessibility of STEM education. Such investments are essential for fostering a skilled workforce capable of driving innovation, economic growth, and societal development in the ASEAN region and beyond. Comprehensive policies should aim to integrate STEM subjects into the national curriculum systematically, ensuring that these subjects are taught from primary through secondary education. Curriculum reforms need to emphasize hands-on, experiential learning approaches that encourage critical thinking and problem-solving. These reforms should also ensure that STEM education is relevant to the needs of the modern workforce, incorporating the latest technological advancements and industry requirements. Teacher training initiatives are critical to the successful implementation of STEM education. Continuous professional development programs can equip educators with the necessary skills and knowledge to teach STEM subjects effectively. These programs should focus on modern teaching methods, the use of educational technologies, and strategies for engaging students in STEM learning. Additionally, fostering collaboration and knowledge sharing among ASEAN member countries can further strengthen STEM education initiatives and promote regional development. By learning from the successful strategies of early adopters like Singapore and Malaysia, Vietnam can adopt best practices and avoid common pitfalls. Collaborative efforts can also lead to the development of regional standards and frameworks for STEM education, enhancing the overall quality and consistency of education across the region. In conclusion, by addressing the existing disparities in STEM education through targeted investments in policies, curriculum reforms, and teacher training, Vietnam can ensure that STEM education becomes a core component of its educational system. This will enable the country to build a skilled workforce ready to meet the challenges of the 21st-century economy, driving innovation and contributing to the sustainable development of the ASEAN region.

Regional peers such as China, Singapore, and Malaysia have successfully integrated STEM education through systematic efforts and the establishment of dedicated STEM schools. For instance, Singapore's implementation of its STEM Education Quality Framework in 2008 led to the establishment of over 300 schools with dedicated STEM programs by 2015. Similarly, China's 2010 STEM Action Plan resulted in the creation of over 500 specialized STEM

high schools by 2015 (Ha et al., 2020; Meng et al., 2022; Tseng et al., 2013). These examples underscore the importance of context-specific strategies and cross-national collaborations for effective STEM education. Political commitment and public-private partnerships play crucial roles in achieving STEM education goals, highlighting the need for tailored approaches within the ASEAN context (Xie & Killewald, 2012). The success of these countries illustrates the critical impact of dedicated policy frameworks and substantial investments in education infrastructure. Singapore's and China's advancements demonstrate how targeted government initiatives can facilitate the widespread adoption of STEM education, foster innovation, and cultivate a skilled workforce. Malaysia, focusing on improving science and mathematics education, has also made significant strides by introducing English as the medium of instruction in 2003, aiming to enhance students' proficiency and global competitiveness. These regional examples highlight several key factors for successful STEM education integration: the necessity of political commitment, the strategic use of public-private partnerships, and the implementation of tailored, context-specific strategies. Political commitment ensures sustained support and resource allocation for STEM initiatives. Public-private partnerships bring in additional resources, expertise, and innovative approaches that can supplement public education systems. Tailored approaches that consider local contexts, such as cultural norms, economic conditions, and existing educational frameworks, are essential for the successful adaptation and implementation of STEM programs. In conclusion, learning from the effective strategies employed by regional peers, Vietnam can enhance its STEM education ecosystem by adopting similar systematic efforts. This involves developing a comprehensive policy framework, investing in education infrastructure, fostering political commitment, and leveraging public-private partnerships. Such strategies will enable Vietnam to create a robust STEM education system that prepares students for the demands of the modern workforce and contributes to sustained economic growth and competitiveness within the ASEAN region (Ha et al., 2020; Meng et al., 2022; Tseng et al., 2013).

Approaches to Curriculum Integration

Vietnam is in the early stages of integrating STEM education into its educational system, and it is currently exploring innovative methods such as engineering design thinking and the use of technology. This initial phase contrasts sharply with the more advanced and established approaches seen in countries like Singapore and China. Singapore, for example, introduced the STEM Education Quality Framework in 2008. This framework laid the foundation for the establishment of over 300 schools with specialized STEM curricula by 2015. These schools have adopted comprehensive STEM programs that are well-supported by government policies and funding, leading to consistently high student performance in international assessments.

Similarly, China has been promoting STEM education since the 1990s, with a significant focus on expanding elite STEM high schools. The number of such schools increased from 100 to over 500 by 2010 (Meng et al., 2022). China's approach includes substantial investments in infrastructure, technology, and teacher training, creating an environment that fosters scientific inquiry and innovation from an early age. This long-term commitment has resulted in a robust STEM education system that produces a large number of graduates skilled in science, technology, engineering, and mathematics.

Malaysia has taken a different but equally strategic approach by focusing on advancing science and mathematics education in secondary schools. Since 2003, Malaysia has taught these subjects in English to improve proficiency and better prepare students for the global job market (Tseng et al., 2013). This policy has been supported by continuous curriculum updates and teacher training programs aimed at enhancing the quality of STEM education.

In contrast, Vietnam and Thailand have faced significant challenges in integrating STEM education into their educational systems. As of 2018 and 2020, respectively, both countries had a limited number of schools offering integrated STEM curricula. These challenges include a lack of trained teachers, insufficient resources, and an educational culture that has traditionally emphasized rote memorization over hands-on, inquiry-based learning (Anderson & Tully, 2020; Promboon et al., 2018).

Despite these obstacles, both Vietnam and Thailand are making concerted efforts to promote STEM education, recognizing its critical importance for future economic and technological advancement. Initiatives are being implemented to develop teacher training programs, update curricula, and improve infrastructure. These efforts are supported by both government policies and collaborations with private sector entities, aiming to build a stronger foundation for STEM education.

By continuing to address these challenges and learning from the successful models of their regional peers, Vietnam and Thailand can enhance their STEM education systems. This will not only improve the quality of education but also equip students with the necessary skills to thrive in a rapidly evolving technological landscape, thereby contributing to their respective countries' economic growth and development.

4.2. Discussion

Vietnam's Progress and Challenges

Vietnam has made considerable progress in prioritizing STEM education; however, significant challenges persist in fully integrating it into the core curriculum. The disparity between policy and implementation underscores the necessity for comprehensive reforms and dedicated efforts to make STEM education more accessible and integral to students' learning experiences. Currently, the implementation of policies has not met the expected efficacy, resulting in a substantial gap between policy intentions and actual practice. There is a notable shortage of well-trained STEM teachers, along with a lack of necessary teaching materials and infrastructure. Comprehensive reforms are essential, including curriculum redesign to integrate STEM into core subjects rather than relegating it to extracurricular activities. This approach should emphasize hands-on, experiential learning that fosters critical thinking and problem-solving skills. By embedding STEM education throughout all levels of schooling, students will have consistent and continuous exposure to these critical fields. Additionally, the development of intensive STEM teacher training programs is crucial to ensure educators are equipped with the requisite skills and knowledge for effective teaching. These programs should include professional development opportunities, workshops, and access to modern educational technologies. Learning from successful models in neighboring countries such as Singapore and South Korea can provide valuable insights for Vietnam. These countries have demonstrated effective methods, from teacher training to the development of modern educational facilities. By studying and adapting these models, Vietnam can improve its own STEM education system. Leveraging political commitment and fostering public-private partnerships are also vital. Strong government commitment to advancing STEM education is imperative. Collaborating with businesses and private organizations can provide essential resources and expertise, creating a richer and more diverse learning environment for students. By implementing these reforms and drawing on successful international models, Vietnam can establish a robust STEM education system, equipping students with the skills necessary to meet the demands of the modern workforce. This will prepare students with the skills and knowledge necessary to thrive in a technology-driven world, ultimately contributing to the country's economic growth and development.

Curriculum Redesign: Integrating STEM education into the national curriculum requires a comprehensive redesign that moves beyond extracurricular activities and incorporates STEM principles into core subjects. This approach should emphasize hands-on, experiential learning that fosters critical thinking and problem-solving skills. By embedding STEM education throughout all levels of schooling, students will have consistent and continuous exposure to these critical fields.

Intensive Teacher Training Programs: A critical component of successful STEM education is having well-trained teachers who are equipped with the latest knowledge and teaching methodologies. Developing intensive teacher training programs is essential to enhance educators' skills in delivering effective STEM education. These programs should include professional development opportunities, workshops, and access to modern educational technologies.

Learning from Successful Models: Neighboring countries like Singapore and South Korea provide valuable models for effective STEM education. These countries have implemented systematic approaches to teacher training and developed modern educational facilities that support STEM learning. By studying and adapting these models, Vietnam can improve its own STEM education system.

Political Commitment and Public-Private Partnerships: Strong political commitment is crucial for the advancement of STEM education. Government support ensures sustained funding and policy focus on STEM initiatives. Additionally, fostering public-private partnerships can bring in resources, expertise, and innovative approaches from the private sector. These collaborations can enhance the learning environment and provide students with practical experiences that align with industry needs. By addressing these key areas through comprehensive reforms, Vietnam can bridge the gap between policy and implementation, making STEM education an integral part of its educational system. This will prepare students with the skills and knowledge necessary to thrive in a technology-driven world, ultimately contributing to the country's economic growth and development.

Comparative Analysis and Regional Collaboration

Comparing Vietnam's efforts with those of its regional peers, it is evident that countries like Singapore and China have made significant progress through well-structured policies and extensive investments in STEM education. Singapore has implemented comprehensive STEM education frameworks, supported by substantial government funding and continuous professional development for teachers. This has resulted in a robust STEM education system that produces high-performing students in international assessments. Similarly, China has prioritized STEM education through large-scale investments in infrastructure, technology, and teacher training, fostering a culture of innovation and scientific inquiry from an early age. Vietnam can benefit from regional collaboration by sharing best practices and adapting successful strategies from these countries to its context. For instance, Vietnam can learn from Singapore's approach to integrating STEM into the core curriculum and China's methods for scaling up STEM education initiatives. By engaging in collaborative efforts with regional peers, Vietnam can enhance the effectiveness of its STEM education programs. Such collaboration can involve joint research projects, exchange programs for educators and students, and regional conferences to discuss and develop innovative teaching methods. These initiatives can help Vietnam address its challenges in STEM education, such as the shortage of trained teachers and the lack of resources.

Enhanced Teacher Training: In Singapore, continuous professional development for teachers is a cornerstone of their STEM education success. Vietnam can adopt similar strategies by creating ongoing training programs that keep educators updated with the latest teaching methods and technological advancements. This could involve partnerships with universities and educational institutions from other ASEAN countries to provide training workshops, certification programs, and exchange opportunities.

Infrastructure and Resource Allocation: China's significant investment in educational infrastructure provides a model for Vietnam. By allocating more resources towards building state-of-the-art laboratories, providing access to modern technological tools, and ensuring that even rural schools have adequate facilities, Vietnam can create a more conducive environment for STEM education. Collaborative funding from regional partners and international organizations can support these infrastructure improvements.

Curriculum Integration: Singapore's integration of STEM into the core curriculum is another strategy that Vietnam can emulate. This involves not just adding STEM subjects as standalone courses but embedding STEM principles across all subjects. For example, incorporating technology in humanities classes or applying mathematical concepts in physical education. This holistic approach ensures that students see the relevance of STEM in all aspects of their education.

Addressing Equity in STEM Education: One of Vietnam's significant challenges is the disparity in access to quality STEM education between urban and rural areas. Learning from China's efforts to make education more inclusive, Vietnam can implement policies that specifically target underserved regions. This could include mobile STEM education units, online learning platforms, and scholarships for students from disadvantaged backgrounds. Ensuring that every student, regardless of their geographical location or socio-economic status, has access to high-quality STEM education is crucial for national development.

Promoting Gender Equity: Vietnam can also look to regional examples to promote gender equity in STEM fields. Initiatives such as mentorship programs for girls, outreach activities that specifically target female students, and campaigns to challenge gender stereotypes in STEM can encourage more young women to pursue careers in these areas. Programs that showcase successful women in STEM can provide role models and inspire the next generation.

Public-Private Partnerships: China and Singapore have effectively leveraged public-private partnerships to enhance their STEM education systems. By collaborating with businesses and private organizations, Vietnam can gain access to additional resources, industry expertise, and real-world learning opportunities for students. Companies can offer internships, mentorship programs, and project-based learning experiences that align academic learning with industry needs.

Promoting Innovation and Entrepreneurial Skills: Fostering a culture of innovation and entrepreneurial skills among students is another critical area. Singapore's and China's emphasis on innovation can be mirrored by creating innovation labs, maker spaces, and entrepreneurship programs in schools. Encouraging students to participate in science fairs, hackathons, and start-up competitions can stimulate creativity and practical problem-solving skills.

Joint Research and Knowledge Sharing: Regional collaboration can also extend to joint research projects that address common challenges in STEM education. By participating in regional conferences and forums, educators and policymakers from Vietnam can share insights, learn from their peers, and develop innovative teaching methods. Exchange programs for educators and students can further enhance this knowledge sharing, allowing for the cross-pollination of ideas and best practices. By addressing these detailed areas through comprehensive reforms and regional collaboration, Vietnam can bridge the gap between policy and implementation, making STEM education an integral part of its educational system. This will prepare students with the skills and knowledge necessary to thrive in a technology-driven world, ultimately contributing to the country's economic growth and development.

Future Prospects and Recommendations

Looking ahead, Vietnam should focus on integrating STEM subjects into the national curriculum, ensuring that these subjects are not merely optional or extracurricular but are core components of students' education from an early age. This involves updating existing curricula to include practical and hands-on learning experiences that engage students and develop their problem-solving, critical thinking, and collaborative skills. Moving away from rote memorization towards experiential and inquiry-based learning can help students better understand and apply STEM concepts.

Prioritizing professional development for educators is crucial. Teachers need continuous training and support to effectively deliver STEM education. This includes providing opportunities for teachers to learn new pedagogical strategies, gain proficiency in using modern educational technologies, and stay updated with the latest advancements in STEM fields. Investing in the necessary infrastructure and resources, such as well-equipped laboratories, computer facilities, and access to educational materials, is also essential to create conducive learning environments.

Fostering collaborations between the government, educational institutions, and the private sector can amplify the impact of STEM education initiatives. The government can provide policy support and funding, educational institutions can implement and innovate in teaching practices, and the private sector can contribute expertise, technology, and real-world learning opportunities through internships and partnerships. These collaborations can ensure that STEM education is aligned with industry needs and that students are prepared for future careers.

Promoting gender equality in STEM is another important aspect. Efforts should be made to encourage and support girls and women in pursuing STEM education and careers. This can be achieved through targeted outreach programs, scholarships, mentorship opportunities, and creating an inclusive classroom environment that challenges gender stereotypes.

By investing in teacher training and capacity building, Vietnam can enhance the quality of STEM education. Teachers equipped with the right skills and knowledge can inspire and guide students effectively. Creating more inclusive and effective STEM education environments will ensure that all students, regardless of their background, have the opportunity to excel in STEM fields.

Adopting these strategies will enable Vietnam to build a skilled workforce capable of driving innovation. A strong emphasis on STEM education will position Vietnam competitively on the global stage, as it will have a workforce ready to meet the demands of a rapidly evolving technological landscape and contribute to the nation's economic growth and development.

Future Research Directions

Despite increasing attention to Vietnam's STEM education, significant gaps remain between national goals and classroom implementation. Rigorous empirical research is essential to guide evidence-based policies and interventions for systemic improvement. Key research priorities include:

First, evaluating effective curriculum models for integrated STEM learning at all educational levels is crucial. This evaluation should consider Vietnam's cultural norms, available resources, and desired learning outcomes. By identifying which models are most effective in fostering student engagement, critical thinking, and practical skills, Vietnam can develop a more cohesive and effective STEM curriculum.

Second, it is essential to assess the effectiveness of professional development programs aimed at enhancing teaching practices. This involves measuring the impact of these programs on teacher skills, student engagement, and learning outcomes. Comprehensive assessments will help refine training approaches, ensuring that teachers are well-equipped to deliver high-quality STEM education.

Third, investigating strategies to address sociocultural biases, particularly those affecting girls' participation in STEM fields, is necessary to promote diversity and inclusion. This research should explore interventions that challenge stereotypes and encourage equal opportunities for all students, helping to create a more inclusive STEM education environment.

Fourth, analyzing the role of regional collaboration networks and public-private partnerships in building STEM education capacity is important. By investigating how these collaborations can supplement public investments and provide additional resources, expertise, and opportunities for students and educators, Vietnam can enhance its STEM education infrastructure and support systems.

Fifth, implementing context-specific STEM education reforms is essential. Utilizing research that addresses Vietnam's unique challenges and opportunities, policymakers can develop actionable recommendations based on empirical evidence. Tailored solutions are necessary to meet local needs and enhance the overall effectiveness of STEM education.

Addressing these research priorities will enable Vietnam to make informed decisions, strengthen its STEM education system, and develop a skilled workforce necessary for sustainable economic growth. Evidence-based, context-sensitive research is crucial for revealing solutions that are specifically tailored to local needs and priorities. By focusing on these areas, Vietnam can bridge the gap between national goals and classroom implementation, ultimately fostering innovation and competitiveness on a global scale.

5. CONCLUSION

STEM education is gaining global traction for the 21st century, driven by digital transformation and the need for integrated competencies in science, technology, engineering, and mathematics. In Vietnam, national policies increasingly prioritize STEM education, recognizing its role in developing critical future workforce skills. However, significant gaps exist between policy and practice. Currently, STEM education in Vietnam is primarily found in extracurricular activities, with limited systematic integration into the formal curriculum. Key challenges include inadequate teacher capacity, insufficient resources, sociocultural bias, and difficulties in translating national STEM goals into classroom practices.

To overcome these obstacles, concerted efforts from government, academia, industry, and civil society are necessary. First, investing in teacher training is crucial. Providing continuous professional development opportunities will ensure that educators are well-equipped with the knowledge and skills needed to deliver effective STEM instruction. Second, enhancing resources by improving access to modern educational technologies and well-equipped laboratories will create a conducive learning environment for students.

Third, fostering inclusive environments that address and mitigate sociocultural biases, particularly those affecting girls' participation in STEM, is essential. This can be achieved through targeted outreach programs, scholarships, mentorship opportunities, and promoting positive role models. Fourth, promoting collaborative partnerships between government, educational institutions, and the private sector will provide additional resources, expertise, and real-world learning opportunities, aligning STEM education with industry needs.

These actions will enable Vietnam to bridge the gap between policy and implementation, fully leveraging STEM education to equip its citizens with the skills needed to thrive in the 21st-century digital landscape. By addressing these key challenges and making strategic investments, Vietnam can develop a robust STEM education system that fosters innovation, drives economic growth, and enhances social development.

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