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Opportunities and Challenges of STEM Education in Bhutan: Stakeholders' Perspectives

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Abstract

The National Science Foundation (NSF) of the United States introduced the acronym STEM in 2001, integrating Science, Technology, Engineering, and Mathematics as a key educational reform that emphasises an interdisciplinary approach to learning and teaching. The global focus on STEM has profoundly influenced educational policies, instructional strategies, assessment systems, and curricula in Bhutan, particularly in mathematics, science, and information communication and technology (ICT). This study explored the opportunities and challenges of STEM education in Bhutan using a mixed-methods approach. Findings revealed that while Bhutanese policymakers, curriculum developers, and educators commonly use the acronym STEM to refer to policies and curricula related to mathematics, science, and ICT education, some were unaware that it includes all four disciplines. Key opportunities identified for STEM education in Bhutan include enhancing student learning and achievement, preparing students for real-world challenges, providing career opportunities, and contributing to national development and the economy. The main challenges to implementing STEM education were the need for a comprehensive curriculum, a sufficient STEM teacher workforce, effective instructional methods, and adequate instructional materials and laboratory resources. The study recommends reforming STEM education in Bhutan by developing a comprehensive understanding of STEM principles, designing a strategic framework for curriculum development and implementation, securing resources, and ensuring effective teacher preparation to ensure high-quality STEM education. Additionally, stakeholders should address the identified challenges and leverage the opportunities in STEM education to promote a more sustainable and prosperous future for the country.

Keywords: STEM education; Integrated STEM education; Opportunities; Challenges; Bhutan

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Introduction

In recent years, the acronym STEM, which stands for Science, Technology, Engineering, and Mathematics, has emerged as a foundational element in contemporary education, significantly influencing curriculum, pedagogical strategies, and learning methodologies across these vital disciplines. The National Science Foundation (NSF) of the United States in 2001 coined the acronym STEM education, emphasising an interdisciplinary approach that integrates these disciplines into a cohesive learning experience (Dugger, 2010). Each component of STEM contributes uniquely to the educational landscape: science provides a deep understanding of the natural world, technology fosters innovation and creativity, engineering develops practical problem-solving skills, and mathematics enhances logical reasoning and spatial thinking (Rifandi & Rahmi, 2019). This integrated approach has transformed STEM education into a "meta-discipline," (Ejiwale, 2013) creating a unified system that encourages collaboration and interconnected learning, preparing students to navigate and contribute to an increasingly complex and technological world.

In a nutshell, STEM education represents a significant shift in educational practices for the technological era and has emerged as a critical component in addressing the challenges and leveraging the opportunities presented by globalisation (Kennedy & Odell, 2014; Stohlmann et al., 2012; White, 2014). In a world increasingly defined by technological advancements and innovation, it is essential for individuals to possess 21st-century workforce skills and values. These include creativity, innovation, critical thinking, analytical and problem-solving abilities, technology literacy, communication, and collaboration skills. STEM education, embraced globally as an educational reform, is recognised for its role in imparting these vital skills and values (Blackley & Howell, 2015; Corlu et al., 2014; Sarac, 2018; Stohlmann et al., 2012). STEM education aims to develop a highly skilled workforce equipped to tackle complex challenges and advance sustainability by preparing students for careers in fields such as medicine, technology, agriculture, and industry (Rifandi & Rahmi, 2019). Moreover, it fosters scientifically and technically literate individuals who will contribute significantly to their nation's economy and social well-being (Zollman, 2012).

In response to the global emphasis on STEM education, Bhutanese policymakers, curriculum developers, and educators have increasingly adopted the acronym STEM to refer to educational policies and curricula in mathematics, science, and ICT. The concept of STEM was initially incorporated into the Bhutanese Education System (BES) with the introduction of locally contextualised Integrated Science textbooks for classes VII and VIII in 1999 and 2000, respectively. However, these textbooks did not fully integrate STEM principles, as they simply compiled chapters from physics, chemistry, and biology without promoting interdisciplinary learning. In 2017, the National STEM Olympiad (Royal Education Council [REC], 2020) was launched with the primary objective of inspiring youth and increasing the recognition of science and technology in Bhutan, marking a significant milestone in the history of STEM education in the country.

However, in the BES, the acronym STEM encompasses only science (S), mathematics (M), and ICT as mandatory subjects from the primary to middle secondary level (Class X). The STEM education framework in the current BES is characterised by a segregated, domain-specific approach. Although ICT is a compulsory subject from pre-primary through class XII and is used in learning and teaching, the concept of "technology" remains vaguely defined and is not clearly distinguished from vocational technology. Vocational technology is offered as an optional subject in select schools from Classes IX to XII, but there is no dedicated engineering subject within BES. While some aspects of engineering, such as problem-solving and innovation, are incorporated into science and mathematics courses, there is no comprehensive engineering curriculum available at the school level. Therefore, this study aimed to explore definitions of STEM education in Bhutan and to identify the opportunities and challenges associated with its implementation in Bhutan. The findings are expected to be valuable to policymakers, curriculum developers, practitioners, and other stakeholders interested in advancing STEM education in the country.

Research Questions

This study aimed to explore the opportunities and challenges of STEM education in Bhutan, guided by the primary research question: What are the opportunities and challenges of STEM education in Bhutan? To comprehensively address this overarching question, the study was further structured around the following sub-questions:

i. How do policymakers, curriculum developers, teacher educators, and STEM teachers in Bhutan perceive STEM education?
ii. What kind of policy support are there to help the advancement of STEM education in Bhutan?
iii. What kind of STEM education is currently available in Bhutanese schools?
iv. What opportunities are there to promote and enhance the quality and standard of STEM education in Bhutan?
v. What are the challenges that could possibly obstruct the advancement of STEM education in Bhutan?

Significance of the Study

The outcomes of this study will be extremely useful to all key stakeholders in understanding a clear definition of STEM education in the context of BES. Although many countries have adopted STEM education, approaches vary between segregated and integrated models, with no universal consensus on its definition. The findings of this study will assist education policymakers and curriculum developers in deciding whether to adopt a segregated or integrated approach or even to incorporate other relevant subjects, to enhance student engagement and elevate national standards in STEM education. Additionally, the study will highlight various opportunities for improving the quality and standards of STEM education in Bhutan from the perspectives of stakeholders. The challenges identified will also provide the Ministry of Education and Skills Development (MoESD) with essential insights for developing intervention measures to address and overcome these obstacles.

Literature Review

Definition of STEM Education

The acronym STEM seems unclear to many, as some countries emphasise segregated, domain-specific STEM education, while others prioritise integrated, domain-general STEM education (Struyf et al., 2019). Integrated STEM (iSTEM) curricula combine content and concepts from multiple STEM disciplines into an applied, real-world approach, whereas segregated STEM focuses on teaching each STEM subject in isolation, with knowledge and practice confined to a single discipline (Nadelson & Seifert, 2017). According to Blackley and Howell (2015), iSTEM is the most prevalent interdisciplinary approach, integrating the four disciplines into a cohesive learning and teaching framework that allows learners to engage in relevant, less fragmented, and authentic real-world problem-solving experiences through various learner-centred pedagogies.

Although various models of iSTEM education have emerged around the world, including: Framework for STEM integration in the classroom (Moore & Smith, 2014); Situated STEM learning (Kelley & Knowles, 2016); The Society-Technology-Science-Society (STSS) model (Banks & Barlex, 2014); Learning Standards Framework of STEAM Classes (Korea Foundation and for the Advancement of Science and Creativity, 2016); and The S-T-E-M Quartet (Tan et al., 2019), the actual implementation poses both opportunities and obstacles, as the integration necessitates careful planning and organisation efforts for execution. In Bhutan, for instance, Integrated Science textbooks were introduced for classes VII and VIII in 1999 and 2000 respectively, combining chapters from physics, chemistry, and biology but without cross-disciplinary integration. This approach faced criticism, as teachers struggled to teach content from all three sciences due to a lack of expertise. Sherpa (2007) argues that implementing an integrated curriculum without adequate research was either improper or a hurried move, leading to confusion among teachers and negatively impacting students' science learning.

In addition to STEM, other fields of study relevant to national needs and priorities have been incorporated into the STEM educational frameworks of some countries. For example, STEMC includes computer science and coding, which are vital for future technological advancements (Portz, 2015). In 2011, Korea proposed restructuring STEM education to include "Art," forming the acronym STEAM, a move also seen in the United States, where it was justified by the idea that artistic sensibilities are essential for creating great products (Portz, 2015; Rifandi & Rahmi, 2019). Likewise, Portz (2015) highlighted the use of STREAM, which adds "R" for reading, emphasising that literacy is fundamental to success. Additionally, Australia's tertiary sector uses the acronym STEMM, incorporating "Medicine" into the STEM framework (Timms et al., 2018).

Goals of STEM Education

STEM education, closely linked to human skills development and national economic growth, has become a global priority in educational policy (Montgomery & Fernández-Cárdenas, 2018). Due to its significance, each country sets specific goals and objectives for STEM education, tailored to address its unique economic needs, workforce demands, and technological and scientific advancements. These goals are embedded in national education frameworks and curricula, guiding the development and implementation of STEM programmes and initiatives. The primary aim of these goals is to cultivate innovative mind sets in the current generation by fostering interdisciplinary knowledge and skills relevant to real-life challenges and preparing students for a knowledge-based economy (Corlu et al., 2014). As Portz (2015) notes, unclear goals and purposes for STEM education can hinder effective implementation.

The core of STEM education lies in preparing students for the 21st-century workforce by equipping them with the knowledge and skills necessary for future careers (Kanematsu & Barry, 2016). For instance, in Western Europe, STEM education was introduced to address the shortage of a skilled workforce in STEM fields (Blackley & Howell, 2015). In the U.S., the main goal is to equip all learners with robust science and engineering skills for successful, productive lives, while also fostering the creation of a sustainable planet for future generations (Kanematsu & Barry, 2015). Globally, the overarching objective of implementing STEM education in schools is to prepare a competent future workforce equipped with essential 21st-century skills and techniques (Ejiwale, 2013). However, in some developing countries, the focus of STEM education has been on increasing student participation in STEM fields and developing a qualified workforce (Marginson et al., 2013).

Opportunities of STEM Education

STEM education offers an integrated, interdisciplinary approach that focuses on closing the learning gap by actively engaging students in experiential and hands-on activities, turning them into active participants rather than passive listeners (White, 2014). Struyf et al. (2019) describe a typical STEM classroom as one that is technology-enhanced and student-centred, a setting that effectively fosters meaningful engagement, boosting both motivation and performance. Unlike traditional methods, this student-centred approach in STEM education cultivates a positive attitude toward learning scientific and mathematical concepts (Kennedy & Odell, 2014).

Likewise, STEM education enhances students' curiosity, making the learning process enjoyable, relevant, and lasting (Sarac, 2018). This is largely due to its emphasis on critical thinking, logical analysis, inquiry, and project-based learning, which are central to the STEM approach. Asghar et al. (2012) similarly note that when effectively implemented, STEM education motivates students to actively engage in learning. By incorporating real-life experiences into the classroom and involving students in experimentation, hands-on activities, and experiential learning, STEM education helps them recognise the value and relevance of the concepts, thereby increasing their enthusiasm for learning.

The student-centred strategies of STEM education not only boost students' motivation but also empower them to apply the knowledge they acquire to their everyday lives (Brenier et al., 2012). Cinar et al. (2016) emphasise that students’ ability to connect what they learn in STEM to practical, meaningful contexts enhances the learning experience. This positive link between the STEM approach and effective learning was also observed in a meta-analysis study in Turkey (Sarac, 2018). By helping students relate concepts to their real-world environment, STEM education deepens their understanding and fosters the practical application of their learning. Beyond promoting deeper conceptual understanding, STEM activities help students develop essential 21st-century skills (Corlu et al., 2014; Kennedy & Odell, 2015). Morrison (2006) further adds that acquiring these skills prepares today's children to become the innovators, inventors, and problem-solvers of tomorrow.

STEM education plays a crucial role in shaping students' future careers. According to Breiner et al. (2012), most of the highest-paying jobs in the future will demand a strong mastery of STEM skills. Additionally, proficiency in STEM is linked to economic growth, national security, innovation, and global competitiveness (Breiner et al., 2012). Ejiwale (2013) also highlights that effectively implementing STEM education and preparing a 21st-century workforce can significantly contribute to revitalising the economy.

Challenges of Implementing STEM Education

Implementing STEM education faces significant challenges, particularly related to the competency of teachers who are crucial for effective curriculum delivery and implementation (El-Deghaidy & Mansour, 2015). Poor preparation and a shortage in the supply of qualified STEM teachers have been reported to be challenges even in the United States (Ejiwale, 2013). Portz (2015) emphasises that the quality of STEM teachers is critical for effective implementation of STEM education. Likewise, teachers need deep content knowledge and strong pedagogical skills to help students grasp complex STEM concepts (Timms et al., 2018). The lack of STEM training among teachers leads to low confidence in their subject knowledge, and the reliance on non-specialised teachers to teach STEM classes due to a shortage of STEM specialists further diminishes the effectiveness of STEM education (Montgomery & Fernández-Cárdenas, 2017; Portz, 2015). Further, professional development of STEM teachers is essential to keep them informed on advances in content knowledge, technology, pedagogical practices for effective learning, teaching, and assessments for meeting the needs of diverse learners. According to White (2014), the "T" and "E" of STEM education appear to be stumbling blocks to meaningful STEM education since many STEM teachers don't possess adequate knowledge of the application of engineering (Portz, 2015) and technological concepts. In the United States, the primary challenge is the lack of engineering skills among teachers, who often are not trained to integrate engineering into science education or have limited experience in engineering education (Ejiwale, 2013).

The curriculum is crucial for the successful implementation of STEM education and for retaining students in these fields. To address this, curricula should either place equal emphasis on modern STEM concepts or be revised to better reflect the skills needed in today's world (Ejiwale, 2013; Timms et al., 2018). Sithole et al. (2017) also highlight the importance of bridging the gap between high school and college science curricula, as the lack of certain STEM components in high school contributes to difficulties in higher education STEM learning.

Low student enrolment in STEM education is a significant challenge in some countries. Many students are unable to gain admission to tertiary STEM courses due to poor performance in STEM subjects during middle and high school (Sithole et al., 2017). Additionally, the demanding nature of STEM programmes, which can lead to student exhaustion, further deters participation. Social stigma also plays a role, with the perception that STEM careers are predominantly for men leading to fewer female students pursuing STEM fields (Sithole et al., 2017). Despite the critical role of STEM education in everyday life, student interest in these courses remains low (Timms et al., 2018). Thus, it is essential to motivate and inspire students to engage with STEM subjects, fostering positive attitudes and preparing them for careers in these fields.

Methodology

The study was guided by a social constructivism paradigm because the key objective was to gather baseline data from participants' perspectives that could be valuable for the country's education system. Social constructivism emphasises the importance of understanding situations from the viewpoints of those involved (Creswell, 2015). Therefore, the study's findings were grounded in the perspectives of key stakeholders in STEM education, including education policymakers, curriculum developers, teacher educators, and school teachers. Additionally, policy documents, regulations, and reports related to science, mathematics, and ICT education in Bhutan were analysed and interpreted through a constructivist lens.

The study used an exploratory sequential mixed methods design, beginning with a qualitative phase of data collection and analysis, followed by a quantitative phase, and concluding with the integration of findings from both phases. Qualitative data were gathered through interviews with two officials from the Planning and Policy Division (PPD) and two STEM curriculum developers from the MoESD. Additionally, six policy documents, regulations, and reports related to science, mathematics, and ICT education in Bhutan were analysed.

The insights gained from the qualitative phase informed the development of a survey instrument for the subsequent quantitative phase. Participants in the survey included STEM teacher educators from Samtse College of Education and Paro College of Education, and STEM teachers from primary, lower, middle, and higher secondary schools in rural, suburban, and urban areas of Samtse Dzongkhag. The study involved 55 science, mathematics, and ICT teachers from schools and 14 STEM teacher educators from the two colleges of education.

Data Analysis

Qualitative data from interviews, open-ended questionnaires, and documents such as policy documents, regulations, and reports on science, mathematics, and ICT education in Bhutan, were analysed according to themes derived from the research objectives. Quantitative data from the survey questionnaires were analysed using Microsoft Excel 20 for descriptive statistics. The findings from both qualitative and quantitative data were then triangulated using a joint display, a method that visually integrates data to generate new insights beyond what could be obtained from the separate analyses (Fetters et al., 2013). For confidentiality and identification, participants were assigned alphanumeric codes. Teacher educators were coded as TE1 for Teacher Educator 1, TE2, for Teacher Educator 2. etc., while school teachers were coded as ST1 for School Teacher 1, ST2 as School Teacher 2 and so forth. Officials from the Planning and Policy Division were coded as PPD1, PPD2, and curriculum developers as CD1, CD2, respectively. These codes helped to distinguish whether participants were teacher educators, school teachers, policymakers, or curriculum developers.

Findings and Discussions

The data collected from interviews, surveys, and documents are organised into five key themes: Perceptions of STEM Education, Current Practices in Teaching STEM Subjects, Opportunities in STEM Education, Implementation Framework of STEM Education, and Challenges of STEM Education.

Perceptions of STEM Education

The first research question posed to all stakeholders of STEM education in Bhutan was, "What are your perceptions of STEM education?" Respondents either described their understanding of STEM education or highlighted its benefits. According to the frequency of thematically derived codes, 67 percent of teacher educators (n = 14) and 36 percent of school STEM teachers (n = 55) viewed STEM education as the integration of the curriculum specified by the acronym STEM. Tan et al. (2019) emphasises that understanding how disciplines are interconnected allows teachers to better appreciate whether these links are based on conceptual knowledge, epistemic practices, or social norms aimed at solving specific problems. Consequently, this study suggests that key stakeholders, particularly the curriculum developers at MoESD should align curricula with the STEM framework and strengthen connections between the disciplines it encompasses. Other perceptions shared by respondents included viewing STEM education as an approach that fosters 21st-century skills, emphasising real-world problem-solving, creativity, collaboration, and project-based learning. Additionally, respondents noted that STEM education plays a crucial role in helping students become innovators, globally competent individuals, and contributors to the nation's economy and social well-being.

The global emphasis on STEM education has led policymakers, curriculum developers, and educators to integrate STEM teaching across school curricula, making "STEM" a key term in educational policies worldwide. The acronym, established by the NSF in 2001, represents the integration of science, technology, engineering, and mathematics (Bybee, 2013; Dugger, 2010). However, its interpretation varies, causing confusion among stakeholders. While some view STEM as a collection of separate disciplines, others see it as an interdisciplinary approach (Breiner et al., 2012; Marrero et al., 2014). This broad understanding complicates the design, implementation, and evaluation of STEM programmes, highlighting the need for a clear definition including in the BES. In Bhutan, the term "STEM" is widely used by policymakers and curriculum developers to describe educational outcomes in mathematics, science, and ICT, as reflected in documents like the Bhutan Education Blueprint 2014-2024 (MoE, 2014).

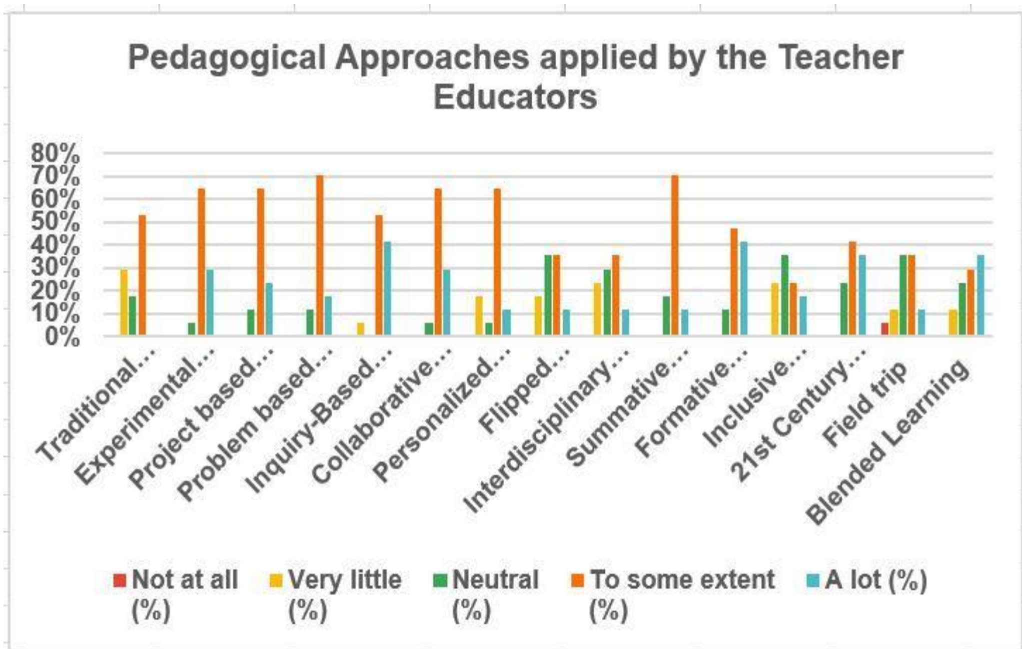
Current Practices of Teaching STEM Subjects

The current practices of teaching STEM subjects in colleges of education and schools have been reported through the pedagogical practices and the use of teaching-learning materials (TLM).

Pedagogical Practices

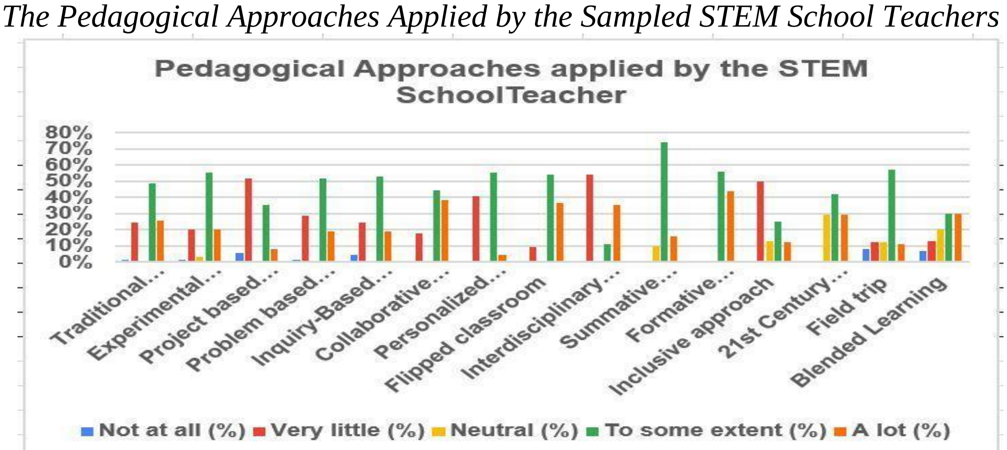
Teachers' pedagogical practices are critical, particularly in addressing the quality of students' learning, which may also influence the student's achievement. The quantitative data revealed that, both teacher educators and school teachers employ a variety of pedagogical approaches, ranging from traditional instructions to emerging pedagogies, including 21st century and blended learning as reflected in Figure 1 and Figure 2. Specifically, the following approaches namely inquiry learning (41%), 21st century pedagogy (35%), collaborative learning (30%) and blended learning (35%), were frequently used by teacher educators from the colleges of education as evident from high rating on the Likert scale **using a lot** as reflected in Figure 1.

Figure 1
The Pedagogical Approaches Applied by the Sampled STEM Teacher Educators



Similar findings were also reported in a study by VanBalkom and Sherman (2010) that the teacher educators in the two colleges of education in Paro and Samtse use the constructivist approach, collaborative learning, and inquiry learning more frequently. Similarly, the pedagogical approaches employed by STEM teachers in schools are predominantly student-centred, as evidenced by the frequent use of experimental teaching (55%), inquiry learning (53%), personalised learning (55%), flipped classrooms (54%), 21st-century pedagogy (42%), field trips (57%), and blended learning (30%), as shown in Figure 2. This transition from traditional teacher-centred methods to student-centred learning highlights the evolving educational practices in Bhutanese schools, a trend also noted by Rabgay (2018) and Childs et al. (2012).

Figure 2
The Pedagogical Approaches Applied by the Sampled STEM School Teachers



Teaching-Learning Materials

Teaching-Learning Materials (TLM), also referred to as instructional materials, are resources that teachers use in educational settings to facilitate the achievement of specific learning objectives. These materials play a crucial role in enhancing the effectiveness of knowledge transfer from educators to students, while also supporting students in learning and comprehending the concepts. This study explored the various types of TLM that teacher educators and school teachers utilise when teaching STEM subjects, as outlined in Table 1.

Table 1
Teaching-Learning Materials (TLMs) used by STEM Teacher Educators and School Teachers

Teaching-learning materials (TLMs)	**Frequency of TLM used by Teacher Educators to teach STEM lessons (n=14)**	**Frequency of TLM used by School Teachers to teach STEM lessons (n=55)**
Paper-based materials	71.4%	92.7%
Audio/video materials	100%	90.9%
Laboratory-based materials	78.6%	67.3%
Real objects, persons, and events	64.3%	65.5%
Presentations (MS PowerPoint)	100%	63.6%
Calculators	50%	38.2%
Web-based software or computer-based simulations	57.1%	27.3%
Online collaborative tools (Padlet, Mentimeter, Jam board, Slido, Kahoot, etc.)	85.7%	18.2%

As evident from Table 1, all the teacher educators (n=14) use audio and video materials and presentations (MS PowerPoint) to support learning and teaching in STEM subjects. Additionally, online collaborative tools like Padlet, Mentimeter, Jamboard, Slido, Kahoot, and others were widely used, with 85.7% of educators incorporating them into their instruction. Likewise, 78.6% of teacher educators used laboratory-based materials frequently. The outbreak of the COVID-19 pandemic led to a significant rise in the use of digital TLMs in colleges of education, particularly through the Modular Object-Oriented Dynamic Learning Environment (Moodle), but this study discovered that educators (71.4%) still preferred to use paper-based TLMs such as textbooks, worksheets, and chart papers during face-to-face teaching as revealed in Table 1. Currently, the integration of e-learning systems to enhance and transform traditional teaching and learning models has become one of the most significant advancements in the use of digital technologies in universities worldwide (Xhaferi et al., 2018).

On the other hand, the most frequently used TLMs by school teachers were paper-based materials (92.7%) and audio/video resources (90.9%), as highlighted in Table 1. In contrast, only

27.3% of school teachers utilised web-based software or computer-based simulations, and just 18.2% used online collaboration tools. This limited use of online platforms in the learning-teaching process may be attributed to the prohibition of mobile devices in classrooms for students. Bhutan's iSherig, the education ICT master plan developed by the MoESD, offers a strategic framework for the integration and utilisation of technology in education (MoE, 2019). MoESD has also undertaken several initiatives to build teachers' capacity in ICT, develop ICT and coding curricula, integrate ICT into learning and teaching, and establish ICT infrastructure (Dorji, 2020). However, despite the country's progress in educational ICT, the restriction on using ICT-enabled mobile devices in classrooms for learning and teaching remains a contentious issue. Allowing students to use mobile devices in the classroom has potential benefits, including internet access for meaningful learning opportunities, seeking assistance with doubts, using online educational tools and apps, and enhancing communication, collaboration, and problem-solving skills (O'Bannon & Thomas, 2015).

Opportunities of STEM Education

As a developing country, Bhutan places high importance on establishing a relevant and rigorous STEM curriculum for all school-aged students. In recent years, growing emphasis on STEM education has led Bhutanese policymakers, curriculum developers, and educators to promote STEM learning through initiatives such as STEM Olympiad competitions, the introduction of a coding curriculum, and the enhancement of educators' professional capacity in technology use. The Bhutan Education Blueprint 2014-2024 (MoE, 2014) underscores the need for school curricula to cultivate 21st-century skills such as innovation, creativity, and enterprise, along with universal human values such as peace and harmony. STEM education, increasingly popular in global educational reforms, is often seen as a key avenue for students to acquire these essential knowledge, skills, and values.

The interview data too revealed that STEM education should be a national priority in Bhutan. The stakeholders believe it is a global educational movement aimed at preparing our youth for future challenges as expressed by one of the Teacher Educators (TE1),"It is a global educational movement that is critical for the next generation to meet challenges in expanding the economy and resolving societal issues." Most participants feel that if Bhutan does not prioritise STEM education now through policies, teacher education programmes, and curriculum, it risks falling behind in the digital age. For instance, School Teacher 22 (ST22) expressed, "As we go into the digital age, it is vital for schoolchildren to comprehend these subjects; otherwise, our country would fall behind, which is why STEM should be a national priority for our country."

Respondents further emphasised that Bhutan can flourish scientifically, technologically, and economically by developing a creative, innovative, skilled, and globally competent workforce through STEM education. However, they stressed that educators must help children understand that excelling in STEM subjects does not necessarily mean they will become "white-collar professionals like engineers or doctors," but rather "social problem solvers." For instance, TE11 expressed that "students should not only strive to become engineers or doctors but also be able to alter society with their knowledge for the betterment of not only themselves but of society and the country as a whole."

Additionally, some respondents (TE and ST) noted that the MoESD's emphasis on STEM education is timely, as it not only promotes hands-on, experiential learning among students but also supports the nation's economic development. They believe that Bhutan's future is closely tied to the advancement of STEM education. The key themes identified by stakeholders regarding the opportunities of STEM education include: enhancing student learning and achievement, equipping students with the knowledge and skills to tackle real-world challenges, offering career prospects, and contributing to the country's overall development and economic growth.

While STEM education equips youth to become scientifically and technologically literate, making them more employable and able to contribute to the nation's economy and social well-being (Zollman, 2012), a significant number of Bhutanese student’s dislike STEM subjects, leading to widespread underperformance, which has become a national concern. Over the years, Bhutanese students' performance in mathematics and science has consistently been disappointing across all grades, particularly in Class X and XII (BCSEA, 2018; 2019a; 2020). Similarly, Bhutanese students performed below average in the 2017 Programme for International Student Assessment for Development (PISA-D) exam, which assessed 2,457 students in classes VII and above to benchmark their competence in science and mathematics literacy at an international level. Bhutanese students scored 45.10 percent in science literacy and 38.84 percent in mathematics literacy (BCSEA, 2019b). The PISA-D report recommends enhancing competency-based activities during the teaching-learning process. As a result, teacher educators and school teachers believe that strengthening STEM education will improve students' learning and help them achieve the desired learning outcomes.

Several factors contribute to Bhutanese students' declining interest in STEM subjects, including content-heavy curricula, abstract concepts, fragmentation and discontinuity in the current curriculum (Childs et al., 2012), challenging subjects that rely heavily on rote memorisation, limited opportunities to apply learned concepts, and a lack of clarity about the connection between subjects and career opportunities. In contrast, STEM education integrates concepts that are typically taught separately, focuses on the practical application of knowledge and skills to real-world problems, and emphasises project-based learning (Forawi, 2018). Consequently, STEM education has the potential to foster meaningful learning and help students achieve the necessary level of competency. Therefore, it is imperative to reform Bhutan's secondary school curriculum to emphasise scientific inquiry, critical thinking, problem-solving, and hands-on learning. Such reforms would enhance student learning and achievement, equip them with the skills needed to tackle real-world challenges, provide career opportunities, and contribute to the country's development and economic growth.

Implementation Framework of STEM Education

The current BES provides domain-specific STEM education, with only science (S), mathematics (M), and ICT included as mandatory core subjects from primary through middle secondary level (Class X). Despite this, documents such as the Bhutan Education Blueprint 2014-2024 (MOE, 2024) and the Curriculum Frameworks (DCPD [Department of Curriculum and Professional Development], 2022) have frequently used the term "STEM" to refer to educational outcomes related to mathematics, science, and ICT. This study found that STEM teachers (n = 55) from Samtse Dzongkhag believe that the framework for STEM education in Bhutan should fully integrate the subjects represented by the acronym. Additionally, 71 percent of STEM teacher educators (n = 14) favoured an integrated STEM (iSTEM) approach, while 29 percent supported maintaining a segregated approach to STEM education.

Similar to the ambiguity surrounding the definition of STEM education, the debate over whether to offer STEM education in an integrated or segregated manner has caused confusion among stakeholders in many countries. In this study, 47 percent of school teachers supported an iSTEM curriculum, while 53 percent preferred the current segregated approach. The preference for segregation stems from the belief that it allows students to focus on the fields they are passionate about, whereas an integrated curriculum might require them to study concepts they are less interested in. In the current BES, students attend separate lessons in science, mathematics, and ICT, each taught by a teacher specialised in that subject. Students are instructed in the content and skills required within a single discipline and are assessed by the same teachers, except in cases of national board examinations. In contrast, iSTEM involves teaching content from two or more STEM disciplines in a real-world context, guided by practices that promote cross-disciplinary connections (Kelley & Knowles, 2016).

According to Tan et al. (2019), STEM education has gained momentum as a cross-disciplinary curriculum designed to equip students with the knowledge and skills needed to tackle complex issues such as climate change, food security, energy security, and cyber threats. Unlike traditional ‘segregated’ STEM, iSTEM blends content and concepts from multiple STEM disciplines, enabling students to apply knowledge and processes from various fields simultaneously in the context of a problem, project, or task (Nadelson & Seifert, 2017). There is no global consensus on the best approach to integrating STEM disciplines, as integration is typically executed through multidisciplinary, interdisciplinary, and transdisciplinary methods. Different countries have adapted STEM education to address their specific needs, and similarly, stakeholders in Bhutan have proposed incorporating or integrating cutting-edge disciplines into STEM education, as outlined in Table 2.

Table 2
Recommended Cutting-edge Disciplines for Inclusion in Bhutan's STEM Education Curriculum

Category	**% of School Teacher Respondents (n=55)**	**% of Teacher Educator Respondents (n=14)**
Environmental Education	40	57
Agricultural science	53	57
Artificial Intelligence and Robotics	51	71
Arts	18	21

In response to His Majesty the King's call for education reform through the *Royal Kasho* (decree), stakeholders in Bhutan, including education policymakers, curriculum developers, teacher educators, and teachers must first understand the goals of STEM education before implementing reforms. Given the strong emphasis on STEM education reform and its significance, it is crucial to align with these goals, as goals will guide instructional design and shape educational programmes. Hsu and Fang (2019) identify two key goals of STEM education: developing a skilled STEM workforce and meaningfully engaging students in STEM subjects. Therefore, it is essential to clearly define the goals of STEM education for Bhutan and to design an effective framework for its implementation.

Challenges of STEM Education

The introduction of STEM education faces several challenges, such as developing a qualified STEM teacher workforce, creating a comprehensive curriculum, implementing effective instructional methods, ensuring the availability of instructional materials, and meeting students' learning objectives (Timms et al., 2018). Similarly, the consequences of adopting a specific STEM education model in Bhutan were studied through curriculum design, human resource and teacher preparation, availability of infrastructure, instructional materials, and laboratory resources.

The head of the STEM curriculum unit at MoESD has indicated that there are no immediate plans to revise the curriculum under the iSTEM model, as the current science, mathematics, and ICT curricula already offer sufficient opportunities for students to apply their knowledge and skills to real-world problems. However, 67 percent of teacher educators and 36 percent of school teachers believe that STEM curricula should be interdisciplinary, rather than the current disciplinary-based approach to science, mathematics, and ICT. Likewise, Tan et al. (2019) emphasise that effective STEM education requires creating stronger connections between the four STEM disciplines, so any integration efforts must be carefully managed to preserve the unique epistemic, conceptual, and social norms of each discipline.

Bryan et al. (2015) define iSTEM as the incorporation of engineering and engineering design techniques into the teaching of science and mathematics content and practices and recommend including engineering and technology, along with ICT, in the development of STEM curricula. Kelley and Knowles (2016) compare scientific inquiry, mathematical reasoning, technology, and engineering design to four pulleys working in perfect harmony to support and elevate STEM learning and practice. However, implementing engineering design education in BES presents significant challenges, as engineering is not yet part of the school curriculum. Currently, TVET courses are available as an optional subject for classes IX and X at only five schools near technical training institutes. Additionally, practicing teacher educators and school teachers generally lack knowledge in engineering education. The existing curricula for both teachers and students do not sufficiently emphasise the practical application of STEM knowledge and skills, as shown in Table 3.

Human resource limitations also exist in the current community of educators when it comes to handling iSTEM education. Teacher educators typically specialise in either science, mathematics, or ICT, with MEd graduates also focused on a single STEM field. Postgraduate diploma in education (PgDE) graduates after 2019 similarly possess expertise in only one STEM area. B. Ed secondary education graduates are the only ones qualified to teach two subjects, such as mathematics and physics, mathematics and ICT, biology and chemistry, or physics and chemistry. When the MoESD introduced Integrated Science for Classes VII and VIII in 1999 and 2000, some teachers struggled due to a lack of competence across all three sciences. Additionally, both teacher educators (M=4.19) and school teachers (M=4.00) reported not receiving professional development in iSTEM teaching pedagogy. Teacher educators also mentioned a lack of experience with 21st-century teaching strategies (Table 4). Conversely, teachers showed a neutral response (M=2.93, SD=1.10), reflecting the fact that over 9,000 school teachers participated in a 5-day training on transformative pedagogy as part of implementing Dr. Spencer Kagan's Cooperative Learning structures in 2016 (Wangdi, 2016).

Professional development for STEM educators is essential, depending on their needs and academic backgrounds. Therefore, teacher preparation programmes in colleges of education must evolve in tandem with changes in school curricula. Teacher educators suggest that the curriculum, pedagogies, and frameworks of STEM-related education programmes in colleges should be updated in alignment with any STEM reforms implemented in schools as shown in Table 3.

Table 3
Perspectives on Bhutan's Current Teacher Education Programmes

Statements	N	Min	Max	Mean	SD
Bhutan's teacher education programs place a strong emphasis on improving student teachers' content, pedagogy, and research skills.	14	3	5	4.06	0.75
Student teachers receive specialised training to teach STEM subjects.	14	2	4	2.59	0.80
Teacher education courses are aligned with national curricula, and student teachers learn what they will be teaching.	14	2	5	3.53	0.87
The health and currency of teacher education programmes have an impact on school student performance as well as school organisational health.	14	2	5	4.00	0.94
To realise the *Royal Kasho's* visions, the country's teacher education programmes must also be overhauled.	14	3	5	4.24	0.56

Note: 5= strongly agree, 4= agree, 3= not sure, 2= disagree, and 1= strongly disagree.

The five-point Likert scale was considered as an interval scale, with the following interpretation of mean values: 1 to 1.8 indicates "strongly disagree," 1.81 to 2.60 indicates "disagree," 2.61 to 3.4 indicates "neutral," 3.41 to 4.20 indicates "agree," and 4.21 to 5 indicates "strongly agree."

The majority of participants agreed that Bhutan's teacher education programmes strongly focus on enhancing student teachers' content knowledge, pedagogy, and research skills (M=4.06, SD=0.75). However, most respondents disagreed (M=2.59) that student teachers receive specialised training in teaching STEM subjects during their education at the colleges of education. Ejiwale (2013) emphasises that STEM teacher preparation programmes should prioritise deep content knowledge and strong pedagogical skills to equip teachers to help students gain a thorough understanding of STEM for future applications in their careers and lives. Respondents agreed with the statement that teacher education courses are aligned with the national curriculum, ensuring student teachers are prepared to teach what they will be responsible for in schools (M=3.53, SD=0.87). They also agreed (M=4.00, SD=0.94) that the relevance and quality of teacher education programmes directly impact both student performance and school organisational health.

Educational Innovation and Practice
Vol. 10, January 2025, 1-22

Finally, respondents strongly agreed that to achieve the *Royal Kasho's* vision for education reform, Bhutan's teacher education programmes must undergo significant revisions (M=4.24, SD=0.56).

Classroom and laboratory facilities play a crucial role in creating an effective learning environment for any STEM lesson. However, inadequate facilities and a lack of instructional materials significantly hinder the successful implementation of STEM education across all educational levels, including primary, secondary, and tertiary institutions. Unfortunately, both teacher education colleges and schools are currently facing shortages in essential infrastructure, tools, equipment, and instructional materials, as shown in Table 5. To assess the challenges, they encounter in teaching STEM subjects, STEM teacher educators and school teachers were asked to rate various categories, such as infrastructure quality, ICT resources, pedagogical support, and the availability of educational materials, on a 5-point Likert scale questionnaire.

Table 4
Issues Affecting STEM Teaching, Learning, and Assessments

	Teacher Educators					**School STEM Teachers**				
Statements	**N**	**Min**	**Max**	**Mean**	**SD**	**N**	**Min**	**Max**	**Mean**	**SD**
Lack of well-equipped laboratories for STEM classes.	14	3	5	4.19	0.66	55	1	5	4.38	0.91
Insufficient laboratory equipment, specimen and chemicals	14	3	5	4.00	0.73	55	1	5	4.28	0.79
Insufficient Internet bandwidth or speed	14	2	5	3.19	1.11	55	1	5	4.49	0.75
Insufficient number of Internet-connected computers	14	2	3	2.46	1.13	55	1	5	4.53	0.77
Inadequate technical support in the use of ICT related learning- teaching tools.	14	2	4	3.00	1.03	55	1	5	4.06	0.99
Lack of STEM related pedagogical professional development training for STEM teacher-educators/teachers	14	4	5	4.19	0.40	55	1	5	4.00	0.93
Lack of expertise in using 21st century teaching-learning skills	14	2	5	3.69	0.95	55	1	5	2.93	1.10
The current curricula do not emphasise the practical application of STEM knowledge and skills.	14	2	4	3.44	0.73	55	2	5	3.42	1.04
Lack of reference materials.	14	2	4	3.25	0.86	55	1	5	3.43	1.09

Note: 5= strongly agree, 4= agree, 3= not sure, 2= disagree, and 1= strongly disagree.

Lack of well-equipped laboratories, as well as insufficient laboratory equipment, specimens, and chemicals, are the key issues that STEM teacher educators (M=4.19, SD=0.66) and teachers (M=4.38, SD= 0.91) are currently confronting (Table 4). Integrating laboratory activities with theory lessons has been shown to enhance students' academic self-efficacy in science learning (Lee et al., 2020). However, basic laboratories in schools and education colleges appear to lack the required laboratory accessories, which can hinder effective learning and teaching. In STEM classrooms, instructional materials characterised as two or three-dimensional learning and teaching aids are essential for creating an engaging learning environment and helping students grasp complex concepts. These materials not only capture students' attention and stimulate curiosity but also encourage active participation in the classroom (Achimugui & Onojahii, 2017).

Regarding ICT facilities, teacher educators do not appear to have any issues, but school STEM teachers have expressed several challenges. These include insufficient internet bandwidth or speed (M=4.49, SD=0.75), a few internet-connected computers (M=4.53, SD=0.77), and inadequate technical support for using ICT tools (M=4.06, SD=0.99). The MOE (2019) has unveiled iSherig-2, its second Education ICT Master Plan (2019-2023), which emphasises the widespread use of ICT in learning and teaching, with the goal of transforming Bhutanese students into "nationally rooted and globally competent citizens" through equitable and pervasive use of emerging and relevant technology. iSherig-2 also aims for seamless integration and pervasive use of ICT in curriculum, pedagogy, and assessment for more engaging learning. However, reports of schools lacking sufficient internet-connected computers with adequate internet bandwidth, as well as teachers lacking appropriate technical support in using ICT-related learning-teaching technologies, could be a barrier to widespread adoption of ICT in schools. Teachers' competency levels in using ICT for integrating technology into classroom instruction and assessments should be enhanced through professional training or workshops. Otherwise, "digital immigrant" teachers might face techno-anxiety when attempting to integrate technology into classrooms for "digital native" students. Therefore, it is essential for teachers to continuously update their ICT knowledge and skills to maintain their technological competence (Revilla et al., 2017).

Teacher educators had a higher mean score (M = 4.19, SD = 0.40), indicating that they perceived a stronger lack of STEM-related professional development training compared to school STEM teachers (M = 4.00, SD = 0.93). The lack of professional development in STEM pedagogy is a well-documented challenge. As Luft and Hewson (2014) point out, continuous professional development is crucial for STEM educators to stay updated with new teaching methodologies and technologies. The slightly higher rating by teacher educators may be due to their closer involvement in curriculum design and pedagogical training, while school teachers may have more immediate concerns related to classroom instruction. Teacher educators exhibited a neutral response (M = 3.69, SD = 0.95) regarding the lack of expertise in using 21st-century learning and teaching skills. This suggests that they are becoming increasingly aware of the importance of these skills, as they not only teach them to student teachers but also practice them as part of their own professional development. The lower mean score for school STEM teachers (M = 2.93, SD = 1.10) regarding the lack of 21st-century learning and teaching skills suggests that many teachers recognise the importance of these skills and are already integrating them into their classroom practices. According to Voogt and Roblin (2012), the successful incorporation of 21st-century skills, such as critical thinking and digital literacy, into STEM education requires targeted training programmes. Accordingly, such programmes should be made available for both teacher educators and school teachers to ensure consistent development of 21st-century across all levels of education.

Both teacher educators (M = 3.44, SD = 0.73) and school STEM teachers (M = 3.42, SD = 1.04) indicated that the current curricula lack emphasis on the practical application of STEM knowledge and skills. The relatively close mean scores suggest that both teacher educators and school teachers recognise the importance of connecting theory to real-world applications to enhance student engagement and understanding. Teacher educators reported the lack of reference materials as a neutral concern with a mean of 3.25 (SD = 0.86), while school teachers had a slightly higher concern (M = 3.43, SD = 1.09). Ejiwale (2013) suggests that a lack of accessible, up-to-date STEM resources can hinder effective teaching, particularly in schools with limited budgets. This highlights the need for greater investment in providing updated and accessible STEM reference materials to both teacher educators and school teachers, ensuring that they are equipped to deliver effective, resource-rich instruction across diverse educational settings.

Conclusion

In conclusion, while STEM education offers significant opportunities, it also presents challenges that need to be addressed. In Bhutan, there is an increasing demand for STEM education to align with global economic shifts and ensure sustainable development. STEM education equips students with essential skills and knowledge for a rapidly evolving technological landscape, fostering critical thinking, problem-solving, innovation, and technological literacy. It encourages students to explore diverse approaches to problem-solving and prepares them for future careers. Moreover, STEM education has the potential to tackle pressing global issues, such as climate change, food security, and social well-being by driving technological advancements and sustainable development.

Nevertheless, this study identified several challenges, including the need for a comprehensive curriculum, the availability and preparation of the STEM teacher workforce, effective instructional methodologies, and the provision of adequate instructional materials and laboratory resources. Additionally, the cost of STEM education can be a barrier for some students, limiting their access to essential resources and opportunities. To fully realise the benefits of STEM education, a collaborative effort from educators, policymakers, and the community is crucial.

Therefore, this study recommends that Bhutanese STEM education stakeholders develop a clear understanding of STEM education and develop a strategic framework for its implementation. Stakeholders should also address the identified challenges and capitalise on opportunities to build a more sustainable and prosperous future for the country.

The following recommendations are provided for various STEM education stakeholders:

i. **MoESD:** Establish a clear and unified definition of STEM education to ensure consistency across all levels of the education system. Align curriculum, teaching practices, and assessment methods with this definition to provide a coherent and integrated learning experience.

ii. **Schools:** Develop and implement programmes to ignite interest in STEM subjects from an early age. This could include hands-on projects, STEM competitions, and interactive learning experiences that make STEM subjects engaging and relevant to young students.

iii. **Teacher Educators:** Invest in professional development for STEM educators to improve their pedagogical skills and subject matter expertise. Provide training on emerging STEM teaching methods, including inquiry-based learning, project-based learning, and the integration of technology in the classroom.

iv. **School STEM Teachers:** Incorporate hands-on projects and real-world applications into lessons to engage students. Prioritise continuous professional development to stay updated with innovative teaching methods and technologies. Collaborate with fellow teachers to effectively support and enhance students' STEM learning and development.

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