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FOSTERING STUDENTS' DEEP LEARNING IN STEM-INTEGRATED SUBJECTS: SCIENCE TEACHERS' PERCEIVED BARRIERS IN OSUN STATE, NIGERIA

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Abstract

This study investigates the perceived barriers science teachers face in fostering deep learning in STEM subjects in secondary schools. An explanatory sequential mixed-methods design was adopted to obtain both quantitative and in-depth qualitative insight. A scaled survey questionnaire was administered to 109 science teachers drawn from 40 randomly selected secondary schools, after which five participants were purposively selected for follow-up interviews using a semi-structured interview guide. Quantitative data were analyzed using descriptive statistics, including mean and standard deviation, while qualitative data were analyzed using thematic analysis. The study's findings reveal limited interdisciplinary knowledge and skills for effective STEM integration, insufficient teacher collaboration in identifying content intersections, and differing conceptions of integrated STEM education. The results further highlight the need for stronger professional support structures, as teachers emphasized the importance of collaboration, institutional coaching, and mentoring to enhance deep learning practices. Based on the findings, it is recommended that integrated STEM courses be included in teacher education programmes with a strong emphasis on practical integration strategies and classroom implementation.

Keywords: Deep learning, STEM education, STEM-integrated subjects, Science teachers, Knowledge integration

INTRODUCTION

Educational systems across countries have undergone numerous changes. One such change is the shift from chalk-and-talk to learner-centred curriculum delivery methods (Zhao et al., 2022). This instructional method focuses on developing students' problem-solving and critical thinking skills, which they need throughout their lives (Weng et al., 2022). As schools strive to prepare learners capable of drawing on more than one subject to thoroughly investigate problems and issues of social significance, it is becoming clear that learning individual subjects in isolation from one another, which does not reflect the interconnections in the real world, is unacceptable.

Innovation, resilience, analytical reasoning, and partnership are beneficial skills for learners' survival in the 21st century (Chen & Zhang, 2016). To promote these attributes in the classroom, a consolidated learning perspective, which is the focus of STEM education, has been empirically shown to be an effective way to help students develop multidisciplinary expertise (Kelly et al., 2020). The primary goal of STEM education, grounded in social-constructivist learning theory, is to establish connections between knowledge and skills derived from multiple disciplines and apply this integrated knowledge in real-life situations (Nipyrakis et al., 2025). As opined by Martin-Paez et al. (2019), STEM education is conceived as a scholastic perspective that advances the incorporation of content (expertise, ideas, and/or outlooks) arising from science, technology, engineering, and mathematics to resolve problems of the natural world.

Sharing the same conception, Bardoe et al. (2023) defined STEM education as an academic approach that integrates science, technology, and mathematics, with STEM content taught coherently rather than in isolation. Blending themes enables learners to develop a deep understanding of the content and retain it for extended periods. Learners can relate to one another, thus fostering deep learning (Delahuntty et al., 2021). As Asikainen (2014) explained, an intensive study seeks to enable learners to reflect deeply, cooperate more effectively, and resolve difficulties satisfactorily. It extends beyond superficial understanding and rote learning and is pivotal in enhancing learners' higher-order thinking skills and attributes, allowing them to acknowledge and apply knowledge in significant ways (Faranda et al., 2020).

The productive development of the nation and its ecological and societal impacts are linked to the evolution of skills through STEM education (Kelly & Knowles, 2016). However, developing countries, including Nigeria, still lag in developing learners' STEM skills. As a result, students are denied the opportunity to learn how to plan, organize, stimulate, and execute assignments or research ideas (Weng et al., 2022). The low engagement and interest in STEM education in developing countries can be attributed to a lack of a definitive STEM integration framework and to differing conceptions of STEM education across countries (Bardoe et al., 2023).

Studies have revealed that teachers face numerous challenges in adopting pedagogical strategies that foster students' deep learning of STEM-integrated subjects (Aguilera et al., 2021; Dare et al., 2019). As also observed by Shernoff et al. (2017), tutors who integrate STEM education into their instruction require numerous conferences and training sessions to gain insight into how to effectively integrate STEM content while collectively attempting to solve real-world problems. Unfortunately, teachers who are to teach STEM education are specialists in one or two STEM subjects and thus are not capable of identifying areas of intersection among the four disciplines (Vasquez, 2015).

Surprisingly, previous works on STEM education in Nigeria have focused on the evolution, status, and impact of STEM and STEAM teaching and learning on the country's economic growth (Abiodun et al., 2023; Badmus & Omosewo, 2018; Oyeniran et al., 2023). Other studies focus on Technological Pedagogical and Content Knowledge (TPACK) in preparing teachers to implement STEM education (Adedokun-Shittu et al., 2018; Bello, 2018). Additionally, other studies have focused on gender disparities in undergraduates' participation in STEM (Salman et al., 2018). However, what is under-discussed and largely uninvestigated in STEM education is the set of barriers that make fostering deeper learning in STEM-integrated subjects challenging, and there is limited knowledge about the pedagogical supports teachers need to effectively implement STEM education in the classroom.

Research Questions

The study sought to answer the following research questions:

1. What barriers make fostering students' deep learning of STEM-integrated subjects challenging as perceived by teachers?
2. What do the teachers perceive as needed support to assist them in fostering students' deep learning of STEM-integrated subjects?
3. How do teachers describe their personal experiences and classroom practices in fostering students' deep learning of STEM-integrated subjects?

LITERATURE REVIEW

The pertinent literature is reviewed under the following headings: conceptualization of STEM education, the concept of deep learning, STEM classroom practices, and knowledge integration in STEM education.

Conceptualization of STEM Education

There is a growing emphasis on producing individuals with a solid foundation in various STEM fields and the ability to transition between them seamlessly. Such individuals are highly sought after in today's rapidly changing world economy. This demand led to the emergence of integrated science, technology, engineering and mathematics (STEM) education. Delahunty et al. (2021) consider this approach to education as an encouraging representation of a vibrant learning of 21st-century literacies. As conceived by Martin-Paez et al. (2019), integrated STEM education is a pedagogical perspective that encourages the incorporation of STEM subject matter (ideas, expertise, and/or views) in the solution of natural-world problems. When implementing integrated STEM education, it is not often necessary to incorporate all four STEM disciplines (Stohlmann et al., 2012). Based on their suggestion, Sanders (2009) asserts that a consolidated STEM education is an approach to "analyze instruction and schooling between/among any two or more of the STEM content aspects" (p. 21).

Similarly, Kelley and Knowles (2016) define integrated STEM education as "the outlook to instruction with respect to STEM subject matter of two or more STEM fields, confined by STEM applications within an original context to connect these contents to stimulate learners' learning". When the content of distinct STEM subjects is effectively amalgamated into a single unified paradigm, the engineering component will give students the opportunities to examine mathematics and science in a more meaningful context and help them develop in-depth and logical thinking skills that can be applied to their work and scholastic lives because of its emphasis on the process and design of solutions (Hurley et al., 2024).

On the other hand, the technology aspect allows students to apply what they have learnt by using technological devices (e.g., computers, smartphones, digital cameras) and computer animation (Wan et al., 2023). At the outset of implementing interrelated STEM education, content and concepts from mathematics and science disciplines are taught coherently to help learners successfully apply the knowledge and skills in authentic contexts (Jeskova et al., 2022). Approaching integrated STEM education from this angle will help novice teachers seamlessly integrate distinct STEM subject areas and teach in a manner that reflects the real world, where STEM disciplines merge and interact. Teachers' possession of sound knowledge of integrated STEM education positions them to design STEM lesson plans better, employ student-centred pedagogies, and support 21st-century skills (Mesutoglu & Akgunduz, 2025).

Existing literature (English, 2016; Perignat & Katz-Buonincontro, 2019) has revealed that there are many advantages associated with incorporating STEM education, enabling students to see the relationships between/among STEM subjects and apply knowledge in real-world situations, developing an in-depth understanding of content and retaining it for more extended periods, and assisting students to develop critical thinking, problem-solving, teamwork, and other transferable skills. To achieve this, Vasquez (2013) developed a theoretical framework for integrating the diverse aspects of STEM learning and implementing integrated STEM Education in the classroom. This theoretical framework comprises four levels of integration of the STEM (Science, Technology, Engineering and Mathematics) disciplines, whose details are explained as follows:

Level 1 - STEM Education (Disciplinary): Students learn concepts and skills separately in each discipline. Separate learning activities are designed for each STEM education component (Science, Technology, Engineering, and Mathematics).

Level 2 - STEM Education (Multidisciplinary): Science, Technology, Engineering, and Mathematics are incorporated into a single activity. Students learn concepts and skills separately in each discipline, but with a common theme that ties them together.

Level 3 - STEM Education (Interdisciplinary): Science, Technology, Engineering, and Mathematics are integrated into the same activity. The learning goals transcend individual disciplines, as they involve multiple disciplines. Students learn concepts and skills from two or more disciplines that are tightly linked to deepen their understanding.

Level 4 - STEM Education (Transdisciplinary): Science, Technology, Engineering, and Mathematics are integrated into a single activity. The learning goals transcend individual disciplines, as they involve multiple disciplines. However, unlike interdisciplinary studies, concepts and skills are learnt across two or more disciplines, with a strong emphasis on applying acquired knowledge to solve real-world problems, thereby shaping students' learning experiences.

With the emphasis being shifted from the traditional STEM Education, where science curricula are taught in isolation, to the emerging integrated STEM Education that emphasizes the intersections across disciplines, there is need to revise the existing curriculum, pedagogy, assessment methods and the contents of the Teacher Professional Programme to suit the integrative approach to science instruction (Mao et al., 2024; Giffney, & Lane, 2025). It was observed that implementing an integrated STEM curriculum adds to teachers' burden, as they are expected to support students by making the areas of intersection across multiple disciplines visible to students in difficult situations (Wan, English, So, & Skilling, 2023).

The Concept of Deep Learning

Marton and Saljo (1976) identified root and superficial approaches to schooling as two different ways in which learners process information. According to them, learners adopt two approaches when preparing for an examination. The first approach, which deep learners adopt, involves reading for overall understanding and meaning. The second approach is commonly used by surface learners, who focus on discrete, isolated truths and engage in note-taking. Deep learning (i.e., in-depth learning) is associated with meaningful understanding that encourages an extended retention period of the learned content. It aims to assist learners in acquiring meaningful knowledge by developing a network of interrelated facts, rather than having students memorize isolated pieces of information

(Kovac et al., 2025). This kind of learning also develops learners' ability to retrieve knowledge through memorization of unchallenged material and to apply it to new difficulties in unconventional situations.

Contrarily, Briggs (1999) and Biggs and Tang (2007) conceived surface learning as non-critical knowledge acquisition, with a focus on memorizing unrelated facts, leading to superficial retention of the content being taught. Based on the aforementioned clarification, evidence supports the reinforcement of deep learning, as it implies cognitive logical reasoning and the practical application of this knowledge in real-world scenarios. It forms a web of connectivity between outdated and the latest intelligence frameworks, creating solutions to complex problems through in-depth data analysis and processing. (Weng et al. 2022). Therefore, when fostering students' deep learning during STEM subject integration, the four elements and connotations of deep learning identified by Zhao et al. (2022) should be evident in the integrated lesson. Detailed descriptions of these elements are presented as follows:

1. **Meaningful Learning:** Meaningful learning can be described through five characteristics: (a) learners take an active role in the process; (b) knowledge acquisition is built and constructed, not just reproduction; (c) learning is directed towards objectives; (d) learning occurs in an authentic situation; (e) collaboration among learners is essential.
2. **Knowledge System Construction:** The acquisition of knowledge goes beyond simply the learner's acceptance of knowledge points and encounters with problems or tasks in life. They combine all their knowledge to compare, find similar connections, and build their knowledge system. This series of processes should be their positive will.
3. **Critical Thinking:** The ability to make logical judgments and thoughtful conclusions by relying on credible and objective evidence. It involves rational, reflective reasoning.
4. **Metacognitive ability:** Metacognition is being aware of and regulating one's cognitive process. It is the ability to monitor, assess, and adjust how knowledge is acquired and applied. This includes self-awareness, evaluation, judgment, and modification of one's learning strategies during problem-solving or knowledge processing.

The above-mentioned deep learning elements can be observed in a classroom practice characterized by active learning, real-world applications, inductive teaching and learning, cooperative learning, authentic assessment, and the development of critical thinking skills (Vincent-Lancrin, 2023). In addition, assessment methods that require learners to produce written responses to open-ended questions, rather than selecting one option in a multiple-choice question, have been reported to enhance deep learning (Mao, 2025).

STEM classroom practice and knowledge integration in STEM Education (*I*STEM Education)

In this context, STEM classroom practice refers to a set of methods and curriculum designs grounded in the principles of iSTEM Education (Portillo-Blanco et al., 2025). Applications of these principles are evident in the relationship between teachers and learners within the classroom learning environment, where iSTEM principles, widely recognized as integration, the use of real-world problems, design, inquiry, and teamwork, are featured. These principles are carefully structured to help students develop knowledge from different subject areas and comprehend how they intersect and apply outside the classroom. Such classroom practices aim to foster learners' creativity, problem-solving, and analytical and evaluative skills, preparing them for the challenges and opportunities of the 21st century. This aim can be achieved only by transitioning from the traditional approach to STEM subject teaching to student-centred methods, where the focus of activity shifts from the teacher to the learners. Classroom practices that reflect integrated STEM Education engage in the following instructional practices as previously discussed in the literature (Auerbach & Andrews, 2018; Leung, 2019, 2020; Salvo-Garrido et al., 2022).

1. Enquiry-based learning: students think critically and logically to solve difficulties or problems, probe, innovate ideas, and generate questions during lessons.
2. In real-world applications, STEM concepts are connected to everyday life, such as using mathematics to optimize a budget or science to understand environmental issues.
3. Instructional strategies such as problem-based, inquiry, discovery, and project-based learning present some difficulties for the learners and require them to stimulate or think critically to solve problems. These are rooted in the in-depth learning of STEM content.
4. Teamwork on the part of the learners with respect to individual accountability and self-dependence forms the basis of cooperative learning.
5. STEM role models and mentors, in which professionals from various STEM fields are invited to share their experiences and inspire students to pursue STEM careers.
6. Authentic assessment, in which students' learning is evaluated through relevant, meaningful, and applicable tasks. This type of assessment is not based on standardized tests or predetermined criteria, but on students' demonstration of the meaningful application of essential knowledge and skills in complex and challenging contexts.
7. Reflecting on the learning process, students are asked what they have learnt and the learning strategy they adopted to gather information and learn in casual conversation. This act produces reflective learners capable of integrating new knowledge, referring to what they previously learned, adapting it to their purposes, and translating thought into action.
8. Inclusive and equitable learning environments, in which a supportive and inclusive classroom culture (that encourages participation and engagement from all students, regardless of background or ability) is fostered.

By incorporating these practices, teachers can create an integrated STEM Education environment that prepares students for the challenges and opportunities of the 21st century. If truly 21st-century skills are to be acquired through integrated STEM Education, then learners should not be positioned as passive recipients of information but rather engage in learning activities leading to the cultivation of critical thinking, problem-solving skills, and creativity essential for success in contemporary scientific endeavours (Bhardwaj, Zhang, Tan, & Pandey, 2025).

METHODOLOGY

This study employed a mixed-methods explanatory sequential design (Cresswell & Plano Clark, 2018). The participants were public secondary school science teachers from randomly selected schools in the Osogbo Local Government Area of Osun State, Nigeria. Using proportional sampling, 109 practicing teachers were selected from 40 secondary schools across the two Local Government Areas. A scaled survey questionnaire, consisting of two sections, A and B, was used to gather information and address the research questions. Section A, consisting of 12 items (measured on a Likert-type scale), was designed to collect teachers' perspectives on barriers that make fostering students' deep learning in STEM-integrated subjects challenging. Section B, which consists of 6 items, was designed to gather information and support needed by teachers in fostering students' deep learning. The collected data were analyzed using the mean and standard deviation. A pilot study on the questionnaire was conducted using 60 teachers from neighbouring schools in the local government area. Cronbach's alpha analysis using the split-half method yielded a coefficient of 0.75.

To complement the quantitative study's findings, semi-structured interviews were conducted with five science teachers to collect qualitative data. These interview findings provided insight into the teachers' coping strategies for overcoming barriers to fostering deep learning in STEM subjects. The recorded and transcribed interview data were analyzed using thematic analysis to identify recurring themes (Braun & Clarke, 2019).

RESULTS

The results of the study are presented in line with the research questions:

Research Question 1: What barriers make fostering students' deep learning of STEM-integrated subjects challenging as perceived by teachers?

Table 1: Barriers towards fostering students' deep learning of STEM subjects as perceived by teachers

Items	Mean	SD	Rank
Lack of knowledge and skills needed for STEM integration	4.07	1.20	1
Lack of collaboration among teachers	4.04	1.25	2
Different teachers' conceptions of STEM Education	4.01	1.21	3
Lack of training in STEM education pedagogy	3.98	1.25	4
Lack of a national framework for STEM education implementation	3.94	1.34	5
Students' inability to integrate and apply knowledge and skills	3.91	1.41	6
Time allotment for teaching STEM subjects	3.81	2.46	7
Overcrowded science classrooms	3.78	1.32	8
Limited access to instructional materials, tools, and technology	3.66	1.43	9
Changes in the assessment techniques	2.76	1.32	10
Planning STEM instructional-related tasks is time-consuming.	2.53	1.31	11
Teachers' and Students' dispositions towards deep learning	2.44	1.41	12

Key: 1.00 - 1.50 (Strongly disagree), 1.51-2.50 (Disagree), 2.51-3.50 (Undecided), 3.51-4.50 (Agree) & 4.51-5.00 (Strongly agree

From Table 1, it is evident that the first nine items, with mean scores ranging from 3.66 to 4.07, are significant challenges confronting teachers in fostering students' deep learning of STEM subjects, as respondents agreed. These factors include lack of knowledge and skills, inadequate collaboration, differing teachers' conceptions of STEM education, insufficient training, the absence of a national framework for implementing STEM education, inadequate time allocation, overcrowded classrooms, and limited access to instructional materials. However, factors such as changes in assessment techniques, teachers' and students' dispositions, and long-term planning for STEM instructional tasks were regarded as posing little threat to teachers' efforts to foster students' deep learning, with mean scores of 2.44-2.76. The standard deviations for all items indicate that the respondents are heterogeneous in their responses.

Research Question 2: What do the teachers perceive as needed support to assist them in fostering students' deep learning of STEM-integrated subjects?

Table 2: Supports needed by teachers in fostering students' deep learning of STEM subjects

Items	Mean	SD	Rank
Providing opportunities for teachers to interact with and learn from one another on teaching for deep learning	4.03	1.21	1
Organizing periodic seminars/workshops where teachers can discuss ideas or receive training on how to implement deep learning strategies	4.01	1.21	2
Providing teachers with opportunities to observe their colleagues delivering inspiring lessons that incorporate deep learning.	3.94	1.23	3
Putting in place instructional coaching and mentoring support	3.77	2.02	4
Making a wide range of online professional development courses accessible to teachers via webinars	3.63	1.30	5
Bringing in an outside consultant to present lectures that are centered on deep learning	2.85	1.13	6

Table 2 shows that the teachers consider all six factors to be the most needed support to help them foster students' deep learning of STEM subjects. The mean values for these factors ranged from 2.85 to 4.93, indicating that they are necessary to promote a deep understanding of STEM subjects. These factors include teacher collaboration, exposure to periodic seminars and workshops, classroom observation of colleagues, learning from external resource persons, and participation in online professional courses. However, the standard deviations across all items indicate that respondents are heterogeneous in their responses.

Research Question 3:
How do teachers cope with the barriers in fostering students' deep learning of STEM subjects?
This research question aimed to investigate teachers' coping strategies for overcoming barriers to fostering deep learning in STEM subjects. Responses from the semi-structured interviews with the teachers were analyzed using thematic analysis, which involved identifying key themes and patterns. Participants' interviews were recorded and later transcribed for further analysis (Braun & Clarke, 2020). Only five teachers (n = 5) were interviewed, and the aim was to gain an in-depth understanding of how they cope with overcoming the barriers.

Theme 1: Adaptation and Coping Strategies
This theme highlights the strategies teachers use to overcome challenges and support deep learning in STEM subjects. Three sub-themes were identified: peer collaboration, practical teaching adjustments, and use of digital resources.

Sub-theme 1.1: Peer Collaboration
Based on the results, participants reported that working with their colleagues allowed them to brainstorm, share experiences, and develop innovative ideas for teaching.

T1 (Male with 8 years of teaching experience): *"I like discussing challenging concepts with colleagues; it is an avenue to find ways to explain such topics so that students can understand better.*

T3 (Female with 5 years of teaching experience): *Most times, I team up with other STEM teachers to create resources that can* *help me with examples to teach abstract concepts to my students*.

T5 (Male with 10 years of teaching experience): *Being able to collaborate with other peers is an alternative way to make my teaching effective when my usual approach does not work for a particular concept.*

The overall interpretation is that peer collaboration fosters a supportive environment for teachers, enabling them to share strategies and pool knowledge that promotes deep learning in the STEM classroom.

Sub-theme 1.2: Practical Teaching Adjustments

Most of the teachers emphasized the importance of adapting to different teaching methods to meet students' needs through scaffolding, breaking down complex concepts, and incorporating hands-on learning activities.

T2 (Female with 7 years of teaching experience): *If I notice that students struggle with concepts or formulas, I break them down into smaller steps, using real-life examples to help them understand.*

T4 (Female with 6 years of teaching experience): *I often create simulations or use virtual labs to engage students more during lessons, which helps them better understand theory in action.*

T1(Male with 8 years of teaching experience*): I always make sure I adjust my teaching pace depending on how quickly the learners grasp concepts. Sometimes, I repeat exercises until I have achieved the learning objectives.*

The overall interpretation is that modifying instructional delivery and incorporating practical experience enables teachers to create pathways that facilitate students' learning and retention of STEM concepts.

Sub-theme 1.3: Use of Digital Resources

The teachers also explained that they integrate digital tools and platforms (e.g., YouTube) into their teaching to supplement limited resources and to engage students in self-paced learning.
T3 (Female with 5 years of teaching experience): *I asked my students to watch YouTube videos before class, which helped them understand complex concepts before attending. Students are encouraged to re-watch even after the class has ended*.

T2 (Female with 7 years of teaching experience): *Sometimes, I record my lessons and share them with students who need extra help. They watch them and learn independently*.

T5 (Male with 10 years of teaching experience): *STEM teachers now rely most on educational apps, platforms, or virtual laboratories to reinforce learners' understanding when classroom time is limited.*

The overall interpretation suggests that the use of digital resources helps compensate for inadequate facilities and provides students with opportunities for exploration, fostering independent and deeper learning.

DISCUSSION

The purpose of this study was to identify the barriers to fostering students' deep learning of STEM subjects. Additionally, it examined teachers' perceived need for support in fostering students' deep learning of STEM subjects. Findings from the study indicate that multiple challenges hindered teachers' efforts to foster deeper learning in STEM-integrated subjects. The main factors include teachers' lack of knowledge and skills, lack of collaboration among teachers, differing conceptions of STEM education among teachers, inadequate training, the absence of a national framework for implementing STEM education, insufficient time allocation, overcrowded classrooms, and limited access to instructional materials. These findings agree with the outcomes of numerous previous studies that revealed that teachers' limited background knowledge in STEM and disciplinary orientations as demanded by STEM (Huang et al., 2020), Inadequate stem Infrastructure (Wang, 2011), lack of definitive STEM model or framework (Bardoe et al.,2023), insufficient time to plan and prepare interdisciplinary STEM instructional activities (Margot & Kettler, 2019), lack of curriculum materials that explicitly link, Science, Technology, Engineering and Mathematics (Peterman et al., 2017), and lack of in-depth peer-to-peer interactions on how to identify areas of overlap among STEM subjects constituted serious challenges hindering implementation of STEM education in schools.

To achieve the objectives of STEM education, measures should be implemented to address the challenges revealed in this study. They need to improve pre-service teachers' preparation to teach STEM-integrated subjects, provide adequate STEM Learning and Instructional Materials (LIMs), and develop a curriculum framework that transforms conventional discipline-specific approaches into an interdisciplinary instructional approach, with science and mathematics as anchor disciplines and other disciplines as integrators.

Another important finding that emerged from this study was that teachers' collaboration, exposure to periodic seminars and workshops, classroom observation of their colleagues, learning from external resource persons, and participation in online professional courses centred on STEM pedagogies were considered by the participants as needed supports to pedagogically equip them to foster deep learning of STEM integrated subjects. This finding aligns with earlier studies (Darling–Hammill et al., 2019), which found that in-service teachers should be provided opportunities to observe out-of-district teachers, have more time for teacher collaboration, and observe examples of how students' deep learning in STEM-integrated subjects can be facilitated. The findings of this study also corroborate those of Shernoff et al. (2017), who found that teachers who incorporate STEM education into their teaching require exposure to several courses and workshops specifically designed to show them how to integrate STEM subjects to solve real-world problems collaboratively. This result also aligns with Pfeffer and Sutton's (2000) argument that teachers can be supported through the adoption of the Observation-Discussion-Reflection (ODR) approach, which provides a framework for sharing discussions, reflections, and observations on fostering deep learning in STEM subjects.

Regarding coping strategies, the teachers indicated that they address barriers to fostering deep learning in STEM subjects by collaborating with colleagues, making practical adjustments, and integrating digital resources. This aligns with the findings of Margot & Kettler (2019), who suggest that among the supports that assist teachers in implementing STEM innovations are collaboration with their peers and professional development. Similarly, it aligns with Berry et al. (2025), who found that teachers with strong content knowledge across various STEM fields tend to collaborate with colleagues who also possess contemporary strengths across disciplines. These coping mechanisms demonstrate that teachers can engage meaningfully with STEM content despite resource constraints.

For effective implementation of STEM education, necessary professional supports should be given to teachers to review their units of work and lesson plans in line with STEM pedagogical practices to give students the opportunities to actualize the continuum in knowledge, integrate the latest knowledge, ensure an extended period of memory of knowledge and comprehension, and actively apply knowledge into effective and efficient learning. The successful teaching of STEM-integrated subjects is hinged on teachers' capabilities in fostering deep learning through the following ways: (a) ensuring students participate in activities that allow them to investigate concepts and formulate solutions to relevant, real-world issues (b) allowing students to demonstrate their understanding by creating a product (e.g., a new app) out of their project engagement (c) giving students opportunities to collaborate and complete tasks with others thereby enhancing deep learning and helping to prepare them for working with others successfully in future and (d) encouraging students to take ownership of their education by helping them understand learning objectives, how they can achieve them and how to measure their success.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This article explores the perspectives of practicing secondary science teachers on the barriers and pedagogical supports associated with fostering deep learning in STEM education. Teachers' lack of interdisciplinary knowledge and skills for integrating STEM subjects, the lack of collaboration among teachers in identifying content-area intersections, and the different conceptions of integrated STEM education among teachers were identified as key barriers that make fostering deep learning challenging. Additionally, as evident from teachers' perceptions, collaboration among teachers, classroom observations of their colleagues, and exposure to periodic seminars and workshops were identified as supports that need to be provided to overcome the identified challenges.

Recommendations

Based on the results of this study, several recommendations can guide the Teaching Service Commission (TESCOM) and the Federal and State Ministries of Education in training in-service science and basic technology teachers in integration strategies and approaches to foster deep learning of STEM subjects. Some of these recommendations are:

1. Science curriculum materials (e.g. textbooks, teachers' guides and students' workbooks) should be redesigned with emphasis on connections and relationships between STEM subjects, and teaching STEM concepts through real-world applications.
2. Concerted efforts should be made towards training teachers to deliver integrated instruction in STEM subjects in isolation. This could be achieved through seminars and workshops.
3. Inclusion of integrated STEM courses into the teacher education programme, which solely emphasizes integration strategies and approaches necessary for implementing STEM education.
4. Concerted efforts should be made by those concerned with Teacher Professional Development to place teachers in industries to experience STEM roles personally; thereby adding to their knowledge in designing STEM teaching and learning activities that promote STEM learning experiences deeply rooted in a real-world context.

REFERENCES

Afolabi, P. A., Lawal, K. B., & Salaudeen, M. D. (2023). Status of science, technology, engineering and mathematics (STEM) education pedagogies in Nigeria. *African Journal of Humanities and Contemporary Education Research*, *10*(1), 203–211.

Adedokun-Shitu, N. A., Abdulkabir, A. I., & Muritala, N. K. (2018). Enhancing STEAM teachers' pedagogical skills using the contextualized approach. In G. Bello, M. T. Mustapha, and M. M. Osokoya, Contemporary issues in science, technology, engineering, arts and mathematics teacher education in Nigeria (pp. 1–10). Biology Education Group, UNILORIN; Unilorin Press.

Aguilera, D., Lupiáñez, J. L., Vílchez-González, J. M., & Perales-Palacios, F. J. (2021). In search of a long-awaited consensus on disciplinary integration in STEM education. *Mathematics*, *9*(6), 597.https://doi.org/10.3390/math 9060597.

Alshehri, E. (2019). Classroom observation for professional development: Views of EFL teachers and observers. Arab World English Journal 1(1), 57 – 71. https://doi.org/10.2139/ssrn.3472192

Asikainen, H. (2014). Successful learning and studying in biosciences. Exploring how students' conceptions of learning, approaches to learning, motivation, and their experiences of the teaching-learning environment are related to study success. *Helsinki: Unigrafia*, *73*-74.

Auerbach, A. J. J., & Andrews, T. C. (2018). Pedagogical knowledge for active learning instruction in large undergraduate biology courses: a large-scale qualitative investigation of instructor thinking. International Journal of STEM Education, 5(19), https://doi.org/10.1186/s40594-018-0112-9

Badmus, O. T., &Omosewo, E. O. (2020). Evolution of STEM, STEAM and STREAM education in Africa: The implications of the knowledge gap. *International Journal on Research in STEM Education*, *2*(2), 99-106.

Bardoe, D., Hayford, D., Bio, R. B., & Gyabeng, J. (2023). Challenges to the implementation of STEM education in the Bono East Region of Ghana. *Heliyon*, *9*(10).https://doi.org/10.1016/j.heliyon.2023.e20416

Bello, G. (2018). Technological pedagogical and content knowledge: the missing link in Nigerian teacher education programme. In G. Bello, M. T. Mustapha, and M. M. Osokoya, contemporary issues in science, technology, engineering, arts and mathematics teacher education in Nigeria (pp. 1–10). Biology Education Group, UNILORIN; Unilorin Press.

Berisha, F., & Vula, E. (2021). Developing pre-service teachers' conceptualisation of STEM and STEM pedagogical practices. In *Frontiers in Education* (Vol. 6, p. 585075). Frontiers Media SA. https://doi.org/10.3389/feduc.2021.585075

Biggs, J. B. (1999). What the student does: Teaching for enhanced learning. International Journal of Phytoremediation, 21(1), 57 – 75https://doi.org/10.1080/0729436990180205

Bhardwaj, V., Zhang, S., Tan, Y. Q., & Pandey, V. (2025). *Redefining learning: Student-centred strategies for academic and personal growth. Frontiers in Education, 10 (1–15)*.

Biggs, J. B., & Tang, C. (2007). Teaching for quality learning at university. Berkshire: Open University Press.

Carvalho, A. (2016). The impact of PBL on transferable skills development in management education. *Innovations in Education and Teaching International*, *53*(1), 35–47.

Chen, M. X., & Zhang, K. L. (2016). Design and implementation of a flipped classroom to promote deep learning among postgraduate students. Modern Distance Education Research, 5, 68 – 78.

Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2019). Creating a continuum of STEM models: Exploring how K-12 science teachers conceptualize STEM education. International Journal of Science Education, 41, 1701 – 1720.

Darling-Hammond, L., & McLaughlin, M. W. (2011). Policies that support professional development in an era of reform. *Phi Delta Kappa*, *92*(6), 81-92. https://doi.org/10.1177/003172171109200622

Delahunty, T., Prendergast, M., & Riordain, M. N. (2021). Teachers' perspectives on achieving an integrated curricular model of primary STEM Education in Ireland: Authentic or Utopian ideology? Frontiers in Education, 6:666608. Doi:10.3389/feduc.202/.666608.

English, L. D. (2016). STEM education K-12: Perspectives on integration. International Journal of STEM Education, 3(1), Article 3.

Faranda, W. T., Clarke, T. B., & Clarke III, I. (2021). Marketing student perceptions of academic program quality and relationships to surface, deep, and strategic learning approaches. *Journal of Marketing Education*, *43*(1), 9-24. https://doi.org/10.1177/0273475320939261

Giffney, S., & Lane, D.(2025). Towards an integrated model of STEM education in secondary schools: perspectives of practicing teachers in Ireland. International Journal of Technology and Design Education. https://doi.org/10.1007/s10798-025-09971-4

Hang, X., Erduran, S., Zhang, P., Luo, K., & Li, C. (2022). Enhancing teachers' STEM understanding through observation, discussion and reflection. Journal of Education for Teaching, 48(5), 576–591. https://doi.org/10.1080/02607476.2021.2006571

Hurley, M., Butler, D., & McLoughlin, E. (2024). STEM teacher professional learning through immersive STEM learning placements in industry: a systematic literature review. Journal for STEM Education Research, 7, 122–152. https://doi.org/10.1007/s41979-023-00089-7.

Jeskova, Z., Lukac, S., Snajder, L., Gunis, J., Klien, D., and Kires, M. (2022). Active learning in STEM Education with regard to the development of inquiry skills. Education Sciences, 12, 686. https://doi.org/10.3390/educsci12100686.

Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teacher self-efficacy for integrated STEM instruction through a collaborative community of practice. International Journal of STEM Education, 7, 1 – 13. https://doi.org/10.1186/s40594-020-00211-w.

Kovac, V.B., Nome, D.O., Jensen, A.R., & Skreland, L.L.J. (2025). The why, what, and how of deep learning: critical analysis and additional concerns. Education Inquiry, 16(2), 237-253, https://doi:10.1080/20004508.2023.2194502

Leung, A. (2019). Exploring STEM pedagogy in the mathematics classroom: A tool-based experiment lesson on estimation. International Journal of Science and Mathematics Education, 17(7), 1339–1358.

Leung, A. (2020). Boundary crossing pedagogy in STEM education. International Journal of STEM education, 7(15), https://doi.org/10.1186/s 40594-020-00212-9.

Mao, G. Zhang, Q., Ma, T., Li, F, & Lan, M. (2024). Investigating how subject teachers transition to integrated STEM education: A hybrid qualitative study on primary and middle school teachers. Humanities & Social Sciences Communications, 11,1059. https://doi.org/10.1059/s41599-024-03565-6

Mao, X. (2025). Online education quality assessment model based on deep learning. Discover Artificial Intelligence, 5(152), https://doi.org/10.1007/s44163-025-004217

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. International Journal of STEM Education, 6(21), https://doi.org/10.1186/s40594-018-0151-2

Martin-Paez, T., Aguilera, D., Parales-Paracios, F. J. & Vilchez-Gonzalez, J. M. (2019). What are talking about when we talk about STEM education? A review of literature. Science Education, 103(4), 799 – 822 https://doi.org/10.1002/sce.21522

Marton, F., &Saljo, R. (1976). On qualitative differences in learning: I – Outcome and process. British Journal of Educational Psychology, 46, 4–11. https://doi.org/10.1111/j.2044-8279.1976.tb02980.x

Mesutoglu, C., &Akgunduz, D.(2025). Integrated STEM Conceptualisations among teachers following a professional development programme. School Science and Mathematics.

Nipyrakis, A., Starvrou, D., &Avraamidou, L. (2025). Examining S.T.E.M Teachers' Design of Integrated STEM lesson plans. International Journal of Science and Mathematics Education, 23, 537-560 http://doi.org/10.1007/s10763.024-10474-2

Oyeniran, E. C., Oyeniran, B. J., Oyeniran, M., & Oyeniran, E. (2023). The role and impact of STEM Education on Nigeria's progress. Asian Journal of Biochemistry. Genetics and Molecular Biology, 15 (4), 31-38.https://doi.org/10.9734/ajbgmb/2023/v15i4350

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. Thinking Skills and Creativity, 31, 31 – 43. https://doi.org/10.1016/j.tsc.2018.10.002

Peterman, K., Daugherty, J. L., Custer, R. L., & Ross, J. M. (2017). Analysing the integration of engineering in science lessons with the Engineering-infused lesson rubric. International Journal of Science Education; 39(14), 1913 – 1931 https://doi:10.1080/0a500693. 2017.13 b9431.

Pfeffer, J. & Sutton, R. I. (2000). The knowing-doing gap. Boston, MA: Harvard Business School Press.

Portillo-Blanco, A., Gisasola, J., & Zuza, K. (2025). Integrated STEM Education: addressing theoretical ambiguities and practical applications. Frontiers in Education. https://doi.org/10.3389/feduc.2025.1568885

Salma, M. F., Salami, O. O., & Dambatta, B. U. (2018). Gender disparity in university undergraduates' participation in science, technology, engineering, arts, and mathematics programmes: Implications for teacher education. In G. Bello, M. T. Mustapha, and M. M. Osokoya, Contemporary issues in science, technology, engineering, arts and mathematics teacher education in Nigeria (pp. 1–10). Biology Education Group, UNILORIN; Unilorin Press.

Salvo-Garrido, S., Sagner-Tapia, J., Bravo-Sanzana, M., & Torralbo, C. (2022). Profiles of Good Teaching Practices in STEM Disciplines: An Analysis of Mixed Methods of Academic and Assessment Variables of Teaching in the First Cycle of Civil Engineering. Frontiers in Education, 7. https://doi.org/10.3389/feduc.2022.849849

Sanders, M. (2009). Integrative STEM education: Primer. 68, Reston: ITEEA.

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher, education, and professional development needs for implementing integrated approaches to STEM Education. International Journal of STEM Education, 4(1), 13. https://doi.org/10.1186/s40594-017-0068-1

Stohlmann, M., Moore, T. J., & Roehrig. G. H. (2012). Considerations for teaching integrated STEM education, Journal of Pre-College Engineering Educational Research (J-Peer), 2, 4.

Vasquez, J., Sneider, C., & Comer, M. (2013). STEM lesson essentials, grades 2-8: Integrating science, technology, engineering, and mathematics. Heinemann.

Vasquez, *J. A. (2015). STEM – beyond acronym. Educational Leadership, 72(4), 10 – 15.*

Vincent-Lancrin, S. (2023). Fostering and assessing student critical thinking: From theory to teaching practice. European Journal of Education, 58, 354–368 https://doi.org/10.1111/ejed.12569

Wan, Z. H., English, L., So, W. W. M., & Skilling, K. (2023). STEM integration in Primary schools: Theory, implementation and impact. International Journal of Science and Mathematics Education 21(suppl 1): S1 – S9 https://doi.org/10.1007/s10763-023-10401-x.

.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. Journal of Pre-College Engineering Education Research (J-PEER), 1(2), 13.

Weng, C., Chen, C., & Ai, X. (2022). A pedagogical study on promoting students' deep learning through design-based learning. International Journal of Technology and Design Education, https://doi.org/10.1007/s10798-022009789-4.

Zhao, D., Li, H., Xu, A., & Song, T. (2022). Psychological mobilization of innovative teaching methods for students' basic educational curriculum reform under deep learning. Frontiers in Psychology, 13. 843 493 https://doi:10.3389/fpsyg.2022.843 493