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Teachers' perceptions of integrative STEM education in life sciences classrooms

Tafirenyika Mafugu [1*], Enosancia Nzimande [1], Cephas Makwara [1]

[1] School of Education, Durban University of Technology, Petermaritzburg, SOUTH AFRICA

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Abstract

The purpose of this study was to explore teachers' perceptions of integrative STEM (science, technology, engineering, and mathematics) education within life sciences classrooms. To achieve this, a case study design was employed, involving three teachers from a single district in South Africa. The data collection methods included face-to-face interviews, analysis of lesson plans, and document examination. The collected data was then analyzed using thematic analysis. The study's findings shed light on the existing challenges concerning the understanding and implementation of STEM education in life sciences classrooms. The teachers demonstrated limited understanding of STEM integration, mainly through the utilization of models. However, the predominant approach observed was traditional teacher-centered methods, which hindered the promotion of critical thinking among students. As a result, this study emphasizes the need for practical implications in terms of teacher professional development. It highlights the importance of higher education training institutions providing ample opportunities for teachers to enhance their ability to effectively implement integrated STEM education in their classrooms. By addressing these issues, educators can create more engaging and stimulating learning experiences that encourage critical thinking and foster a deeper understanding of STEM concepts among students.

Keywords: STEM, integrative, life science, case study, interviews, lesson plans

INTRODUCTION

DeSutter and Stieff (2017) emphasize the significance of spatial thinking as a crucial component of STEM learning. However, existing learning environments that aim to cultivate spatial thinking often fall short. One of the main challenges lies in the lack of pedagogical knowledge among teachers, hindering the seamless integration of STEM education into their classroom practices (Mansour & El-Deghaidy, 2015). In today's world, there is a growing demand for STEM workers (Marrero et al., 2014). To meet this demand and foster future innovation, STEM education becomes paramount as it equips individuals with the necessary skills for prospective employment opportunities (Reynante et al., 2020). Unfortunately, in South Africa, there is a notable scarcity of individuals pursuing technological or scientific subjects, resulting in an economic disadvantage due to the unavailability of skilled workers in these critical fields (Charette, 2013). Regrettably, this skills shortage issue is not confined to South Africa alone but is also prevalent in other countries (Charette, 2013).

STEM education in Indonesia was carried out using learning models like project based learning (PjBL), engage, explore, explain, engineer, enrich, and evaluate (6E), higher order thinking skills assessment based-learning, inquiry, think pair share, problem-based learning (PBL), android game, digital and learner book based-learning. The PjBL is the widely used method in STEM education implementation in Indonesia (Khotimah et al., 2021). However, Permanasari et al. (2021) assert that many teachers do not apply the STEM approach in their classroom practices, leading to weak comprehension of STEM and its integration on the learners' side.

✉ TafirenyikaM@dut.ac.za **(*Correspondence)** ✉ MafuguT@ukzn.ac.za ✉ tmafugu@gmail.com

Contribution to the literature

- This study emphasizes the need for practical implications in terms of teacher professional development.
- It highlights the importance of higher education training institutions providing ample opportunities for teachers to enhance their ability to effectively implement integrated STEM education in their classrooms.
- By addressing these issues, educators can create more engaging and stimulating learning experiences that encourage critical thinking and foster a deep approach to the understanding of STEM concepts among students.

LITERATURE REVIEW

STEM-Based Teaching

In numerous countries, STEM-based teaching is an integral part of school curricula (Bartels et al., 2019). This inclusion reflects a broad aspiration to equip students with the skills necessary to foster economic growth (Prinsley & Johnston, 2015). It is recommended that the development of these skills begin early, starting in early childhood education (Çiftçi & Topçu, 2022). Setyowati et al. (2021) confirm that STEM-based teaching extends across all educational levels, from early childhood to secondary education. Primary schools play a crucial role in progressively developing STEM skills throughout a student's education.

Scholars advocate for educational approaches that encourage students to explore, inquire, solve problems, and engage in critical thinking (Giri & Paily, 2020; Glazewski & Ertmer, 2020). Consequently, reform initiatives within STEM disciplines have increasingly emphasized strategies such as inquiry-based learning (Lai, 2018), PjBL (Aprianty et al., 2020), constructivist learning (Mafugu, 2021), PBL (Rehmat & Hartley, 2020), and the integration of technology across all STEM fields (Roehrig et al., 2021).

Despite its widespread presence in curricula, there is a lack of consensus among teachers and scholars on the precise nature of STEM-based teaching (Marrero et al., 2014). Thibaut et al. (2018) identified nine core tenets of STEM education through a systematic literature review, which include integration approaches, PBL, inquiry, design, teamwork, student-centered hands-on assessment, and a focus on developing 21st century skills. Dare et al. (2019) acknowledge that while there is no unified definition of STEM teaching, common practices are evident. These practices involve connecting STEM disciplines to cultivate 21st century skills through real-life contexts, problem-solving, and learner-centered pedagogies. Integration is a key aspect of STEM education, as real-world problems typically span multiple disciplines. Consequently, STEM-based classroom activities can be multidisciplinary and interdisciplinary through content integration, curricula integration, and context integration (Thibaut et al., 2018).

In interdisciplinary approaches, integration may extend beyond STEM disciplines to include other areas such as social studies, arts, and languages (Bybee, 2010; Sanders, 2009). Incorporating languages enhances students' engagement with STEM-specific discourse and communication (Lee & Stephens, 2020), suggesting that STEM education should consider the language of instruction. Debates involving discourses on subject specific language brings to the fore disciplinary literacies (Hubbard, 2021). Adding the arts to STEM forms the STEAM framework (science, technology, engineering, arts, and mathematics). Wang et al. (2018) argue that fostering high-level talent and innovative skills is crucial for supporting the needs of modern economies. Creativity and talent are believed to enhance skills like engineering design and problem-solving. Integrating arts into STEM education is thought to nurture creativity and talent, leading to the STEAM imperatives (Harris & De Bruin, 2018; Wang et al., 2018). Consequently, the role of the arts in fostering creativity and talent is increasingly recognized. However, English (2017) warns that interdisciplinary approaches should not compromise the integrity of individual disciplines. The examples discussed here are only a few among many possible interdisciplinary approaches in STEM education.

Moreover, interdisciplinary approaches in STEM education can involve integrating technology with other STEM disciplines, merging the learning goals of multiple disciplines, and combining curricula from different disciplines (Dare et al., 2019). Dare et al. (2019) describe a continuum of integration, from teaching STEM disciplines separately to merging all four disciplines into a unified curriculum, with various intermediate options. The multidisciplinary approach allows students to learn STEM disciplines separately, with the expectation that they will make necessary connections (Thibaut et al., 2018). This approach aligns with how STEM education is often implemented in schools, where different subjects are taught in separate classrooms (Bartels et al., 2019).

STEM in the South African context

In the study conducted by Williams (2011) in South Africa, an interdisciplinary approach to education was adopted, grouping science, engineering, and technology (SET) subjects together to promote STEM learning. One of the initiatives that emerged from this approach was the Inkanyezi project, which received funding from the Zenex Foundation and aimed to enhance students' knowledge of science and mathematics (Tikly et al., 2018). Despite these efforts, there remains a gap in the existing literature regarding the implementation of SET and integrated STEM education in South Africa. Therefore, the main objective of this study is to investigate teachers' perceptions and practices concerning the integration of science, technology, engineering, and mathematics education. The research intends to shed light on how STEM education is being incorporated into the South African educational system, exploring the views and approaches of teachers in the process. By gaining insights into teachers' perspectives and practices, the study seeks to contribute valuable information to the ongoing efforts to enhance STEM education in the country.

Bybee (2013) highlights various challenges associated with STEM education, and in Giamellaro and Siegel's (2018) work, it is emphasized that STEM lacks a clear and well-defined academic identity. Giamello and Siegel (2018) reiterate that the lack of a clear and consistent definition of STEM education further hampers its effective integration into instructional settings. Additionally, Timms et al. (2018) concur that the current STEM curriculum is imbalanced, leading to demotivation among both learners and teachers. The ambiguous nature of STEM education leads to frequent misinterpretations when using the term. Thus, it becomes crucial to clarify and precisely define the goals of STEM education for effective instructional purposes (Bybee, 2013). Stohlman et al. (2012) emphasize the significance of providing quality STEM education for the future of learners. However, a critical barrier lies in teachers needing to acquire pedagogical knowledge to effectively integrate STEM education into their classroom practices (Mansour & El-Deghaidy, 2015). To address these issues, it is of utmost importance that all stakeholders gain a comprehensive understanding of STEM's functioning in schools and its identity within the classroom context, which can be achieved through a diverse range of research efforts. A comprehensive understanding of STEM in South Africa and globally is likely to address the shortage of individuals pursuing technological and scientific subjects. This can increase the availability of skilled workers in these critical fields, leading to economic advantages (Charette, 2013).

The quality of STEM education can vary based on the curriculum, teaching methods, and professional development opportunities available to educators. In some cases, outdated or ineffective teaching practices may hinder student engagement and learning. Overall, the study sheds light on valuable insights into teachers' perspectives on STEM integration in education, uncovering crucial factors influencing the successful implementation of STEM education in classrooms. The study aimed to answer the following research question:

What are the teachers' perceptions of STEM education integration in life sciences classrooms?

The objective of the study was to explore the teachers' perceptions of STEM education integration in life sciences classrooms.

THEORETICAL FRAMEWORK

The study utilized the constructivism learning theory as its theoretical framework. Constructivism, according to Fosnot (2005), delves into how individuals acquire knowledge and explores the processes through which people come to know and understand. Bada and Olusegun (2015) further explain that it views learning as an active process where learners construct their own understanding and meaning through social interaction. Obikwelu and Read (2012) outline three fundamental principles of constructivism: individual representation of knowledge, active exploration of knowledge, and learning through social interaction or collaboration. Unlike behaviorist learning theory, constructivism places the learner as an active processor of information.

The integration of constructivism with STEM education is a natural fit, as the innovative STEM curriculum demands active participation through hands-on activities. In this context, the teacher acts as a facilitator, guiding students in real-world tasks and projects. By creating models of real-world products in STEM classrooms, learners gain a deeper understanding of how things work and develop problem-solving skills by tackling complex issues. This aligns with the tenets of constructivism, where new learning builds upon prior experiences and knowledge. Learners are encouraged to take responsibility for their learning by connecting new knowledge to their existing knowledge and experiences (Dennick, 2016). Therefore, integrating constructivism with STEM education becomes essential to provide the necessary foundation and prior knowledge for successful discipline integration in the foundational and intermediate phases of education (Nadelson et al., 2013). Learners draw upon their prior experiences to create new concepts and understanding, allowing for deeper integration of new information.

Raldoff and Guzey (2016) also emphasize the compatibility of constructivism with STEM education, acknowledging the significance of experience and its direct impact on existing knowledge and knowledge acquisition. Sevda and Sevim's (2018) study echoes this sentiment, with teachers attesting that the constructivist approach in STEM education fosters learner-centered teaching and learning processes, considering factors such as learners' development, intelligence, and preferences.

The influence of constructivism on the cognitive process is highlighted by Sayary et al. (2015), who emphasize that it serves as the foundation for PBL. Given the study's exploration of teaching STEM education, the use of constructivist learning theory is well-suited to understand the dynamic interaction between learners, teachers, and the subject matter. Social interaction plays a crucial role in teaching and learning, as collaborative methods allow students to engage with their peers, fostering a deeper understanding of the subject matter and encouraging cooperative problem-solving.

Constructivist strategies provide valuable tools for both teachers and learners to communicate effectively. By acknowledging the learner as an active participant in their learning process, educators can better facilitate meaningful interactions and knowledge acquisition (Powell & Kalina, 2009).

In conclusion, adopting the constructivism learning theory in this study aims to enhance our understanding of how STEM education can be effectively taught, with a focus on empowering learners through active engagement, prior knowledge integration, and problem-solving skill development. Constructivism stands in contrast to behaviorist learning theories by emphasizing the active role of the learner in constructing knowledge. Its principles encourage educators to consider learners' prior experiences and engage in social interaction, creating a more effective and dynamic learning environment.

RESEARCH METHODOLOGY

Research design plays a crucial role as a strategic framework for action, bridging the gap between research questions and the actual execution of the study (Blanche et al., 2006). To inform the chosen research approach, several research designs are available, including case studies, ethnography, and grounded theory. For this study, an exploratory case study was selected to gain valuable insights into the subject under investigation. The case study design is a methodology that allows researchers to delve into complex phenomena within their specific contexts (Baxter & Jack, 2008). According to Yin (2003), exploratory case studies are particularly useful when evaluating interventions that do not have clear or singular outcomes. In this study, the focus was on exploring integrative STEM education as an integrating approach. To maintain boundaries and focus, this case study was conceptually and geographically bound to life sciences teachers in one district in the Free State Province in South Africa. This approach allowed the researcher to gain a deep understanding of individual teachers' perceptions and practices related to integrative STEM education. Guetterman and Fetters (2018) highlight that case studies have a tradition of collecting comprehensive data to understand the subject under study, making it a relevant and suitable design for this research. Another advantage of the case study design is that it provides raw data for independent inspection (Baxter & Jack, 2008). By adopting the exploratory case study design, this research aims to gain valuable insights and a comprehensive understanding of the integration of STEM education among life sciences teachers in a district in the Free State Province.

The study participants consisted of three teachers who had been teaching life sciences in grade 11 and grade 12 for at least two years in three different schools. The participants were coded LST 1, LST 2, and LST 3. LST 1 had two years of experience in teaching both grade 11 and grade 12, while LST 2 and LST 3 had 5 and 7 years of experience, respectively. Semi-structured interviews, observations, and document analysis (lesson plans) were used to gather the data. The interviews were conducted in the teachers' offices within the schools. Arrangements to see the teachers were made after seeking permission from the respective principals, following the acquisition of an ethical clearance letter from the University Ethical Clearance Committee. Permission was also sought from the Provincial Department of Education. Informed consent was obtained from each participant. During the interview process, the researcher sought permission to record the interview, and each of the participants signed an informed consent after being informed about the pertinent information about the study from the researcher. The interviews lasted between 30 and 45 minutes. After the interviews, each participant in-service teacher was observed teaching the topic in the subject. The respiratory system, the mechanism of breathing and plant responses to the environment are the topics that were observed. Lesson plans for the lessons observed were collected for triangulation of the observation and interview data to ensure trustworthiness. Before embarking on the study, pilot testing was done with a teacher who was not participating in the study, to ensure that the interview questions were comprehensive.

RESULTS

Main Theme: Teachers' Perceptions of STEM Education

The study's findings revealed two significant sub-themes:

(1) teachers' understanding of STEM subjects and

(2) readiness of STEM classrooms (**Table 1**).

Each of these sub-themes further comprised several categories. By recognizing these sub-themes and their respective categories, the study gained valuable insights into the challenges and opportunities associated with STEM education, empowering educators to make informed decisions and improvements in their teaching practices.

Sub-theme 1: Teachers' understanding of STEM education

STEM education suffers from an identity problem. This is evident in the manner that the participants

Table 1. Categories of teachers' knowledge of STEM education & preparation of STEM classrooms

Sub-theme & categories
Sub-theme 1: Teachers' understanding of STEM education. This sub-theme encompassed three categories.
Category 1: Obscurity of STEM education for instruction: The first category explored the challenges teachers faced in comprehending the intricacies of STEM education and how to effectively integrate it into their instructional methods.
Category 2: Incorporation of four subject disciplines (science, technology, engineering, and mathematics): The second category delved into how teachers approached the incorporation of the four fundamental subject disciplines that constitute STEM education.
Category 3: STEM initiatives: The third category examined the various initiatives and programs implemented by teachers to enhance their understanding of STEM subjects and improve their teaching practices.
Sub-theme 2: Readiness of STEM classrooms. This sub-theme explores the different ways in which STEM classrooms should be prepared. This sub-theme included two categories.
Category 1: Creating a diversity-accommodating environment: The first category focused on the efforts made by teachers to create inclusive and diverse learning environments within their STEM classrooms, catering to the needs of all students.
Category 2: Addressing practical aspects of STEM classroom preparation: The second category explored the practical considerations and preparations undertaken by teachers to ensure that their STEM classrooms were conducive to effective learning and experimentation.

provided explanations of STEM education. When asked to explain what STEM is, this is how two of the teachers responded:

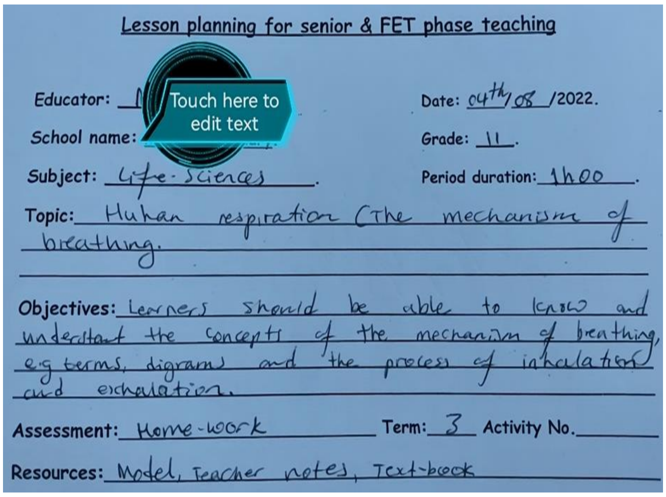
> LST 1: [Uh] STEM education is an integrated approach to teaching and learning whereby learners are exposed to the world of science, technology, engineering, and mathematics.

> LST 3: STEM is science, technology, engineering and mathematics, and it is a broad term used to group the four subjects.

The lesson plan in **Figure 1** belongs to LST 1, who presented the lesson of the day.

This is a clear indication that LST 1 and LST 3 did not comprehend what STEM education for instruction entailed judging from how they vaguely provided an explanation for STEM education. The limited knowledge of what STEM is for instructional purposes is also seen in how LST 1 structured his lesson plans (**Figure 1**), which showed no adoption of various learning styles. Furthermore, looking at the lesson plan, it was clear that the objectives set for the lesson in question were also vague. However, it was thrilling to see the teacher using materials in the classroom which was written in the plan.

LST 1 also conducted lessons that were teacher-centered. However, the teacher used models (**Figure 2**)


Lesson planning for senior & FET phase teaching

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Educator:

Date: 04th/08/2022.

School name:

Grade: 11.

Subject: Life-Sciences.

Period duration: 1h00.

Topic: Human respiration (The mechanism of breathing.

Objectives: Learners should be able to know and understand the concepts of the mechanism of breathing, e.g terms, diagrams and the process of inhalation and exhalation.

Assessment: Home-work Term: 3 Activity No.

Resources: Model, Teacher notes, Text-book

Figure 1. LST 1's lesson plan (Source: Authors' own elaboration)

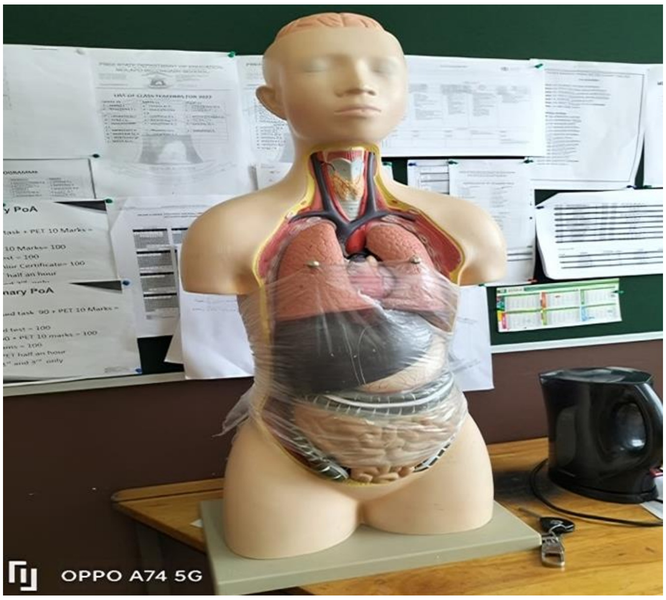


Figure 2. LST 1's teaching model (Source: Authors' own elaboration)

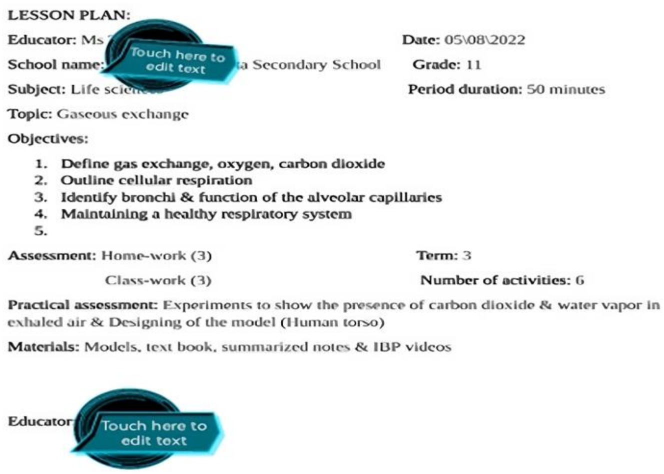
in the classroom to provide a clear demonstration of what he was talking about even though learners only observed the model from a distance as it was observed by the researcher. LST 1 was teaching human respiration and brought to class the human torso to show learners the organs responsible for breathing (**Figure 2**).

The researcher also observed that learners were overcrowded (**Figure 3**), and others could not see the model as the teacher was waving it in front to show the various bones he was referring to. The manner in which learners were seated allowed them to hold mini-discussions; brainstorming, come up with their own possible solutions, and conclude on the best idea\solution learning from each other (**Figure 3** and **Figure 4**). Additionally, it was worth noting that the teacher searched for prior knowledge at the beginning of the lesson to remove myths that could possibly hinder learning in any way.

Figure 3. LST 1's seating plan (Source: Authors' own elaboration)

Figure 5. LST 2's seating arrangements (Source: Authors' own elaboration)

Figure 4. LST 3's seating arrangements (Source: Authors' own elaboration)



LESSON PLAN:
Educator: Ms
School name: a Secondary School
Subject: Life sci
Date: 05\08\2022
Grade: 11
Period duration: 50 minutes
Topic: Gaseous exchange
Objectives:
1. Define gas exchange, oxygen, carbon dioxide
2. Outline cellular respiration
3. Identify bronchi & function of the alveolar capillaries
4. Maintaining a healthy respiratory system
5.
Assessment: Home-work (3)
Class-work (3)
Term: 3
Number of activities: 6
Practical assessment: Experiments to show the presence of carbon dioxide & water vapor in exhaled air & Designing of the model (Human torso)
Materials: Models, text book, summarized notes & IBP videos
Educator
Touch here to edit text

Figure 6. LST 3's lesson plan (Source: Authors' own elaboration)

Like LST 1, LST 3 (**Figure 4**) has her learners seated in pairs, indicating that learners do construct knowledge among themselves as peers and through socialization.

Contrary to the seating arrangements of LST 1 and LST 3, LST 2's seating arrangements indicate that learners were seated individually, each doing his/her own thing, against the principle of a constructivist classroom (**Figure 5**). There were no group activities to promote learner-learner interaction.

The lesson plan constructed by LST 3 (**Figure 6**) was inclusive of STEM education as it indicated that the lesson would be conducted through models, charts and project-based activity facilitated in class, where learners would be designing structures involving gaseous exchange and demonstrate how gases move between air and blood in the lungs. During this lesson, the researcher observed an impressive lesson which included charts, models and mini-videos meant to enhance learners' comprehension of the topic in question. The lesson conducted by LST 3 was in line with what is stipulated in the lesson plan. However, learners were given the project to design at home because the time was limited in the classroom to do so. However, the use of integrated business planning videos was not done during the lesson despite the indication of it being incorporated.

LST 2 provided a detailed explanation of what STEM is by responding to STEM education as:

> LST 2: STEM refers to a teaching and learning tool that is immensely vital in a manner that it integrates the four subjects\disciplines that are science, technology, engineering and mathematics, into a cohesive interdisciplinary and applied learning approach.

The explanation provided by LST 2 differed from the ones provided by the preceding participants because this one particularly comprehended what STEM education was and its identity for instructional purposes. However, the lesson plan structured by this teacher was in contrast to the knowledge he had of STEM education. His lesson plan lacked concrete information on how STEM education lessons were prepared, with no indication of extra tools to be used in the classroom. The objectives of the lesson were not aligned to any other discipline to show that the integration of two or more disciplines would take place. Furthermore, the teacher was fully knowledgeable, but the lessons were not in line with STEM education integration. The actual lessons contrasted with the knowledge that the teacher had about STEM education. This led to the conclusion that the problem was with the incorporation of STEM education in the lesson as Mansour and EL-Deghaidy (2015) pointed out that teachers struggle with the integration of STEM disciplines in their lessons.

Incorporation of four subject disciplines: It was common among the three teachers that STEM education comprised the four subject disciplines. LST 1, LST 2, and LST 3 had the following to share:

> LST 1: STEM education is an integrated approach to teaching and learning whereby learners are exposed to the world of science, technology, engineering and mathematics.

> LST 2: STEM refers to a teaching and learning tool that is immensely vital in a manner that it integrates the four subject\disciplines which are science, technology, engineering and mathematics.

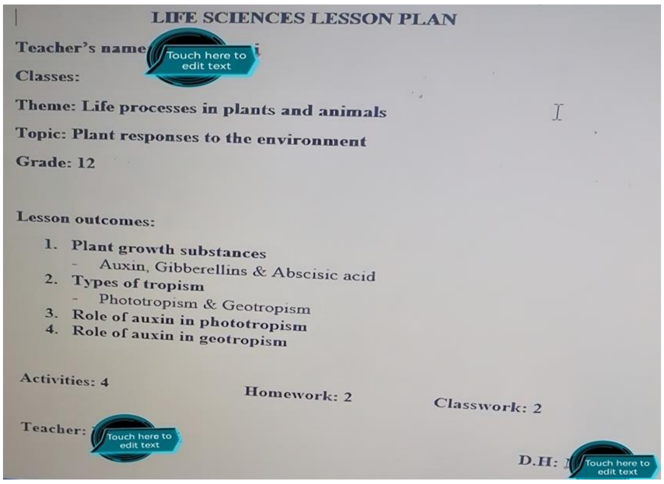
> LST 3: STEM is a science, technology, engineering and mathematics program. It is a broad term that is used to group together these academic disciplines, which are integrative in nature.

Although the teachers spoke about integrating the subjects, there was no clarity on the integration of the disciplines in one lesson. The teachers collectively had a common understanding that STEM education was an educational tool that included four subjects which should be integrated.

STEM initiatives: Teachers' perceptions of STEM education initiatives for instructional purposes varied greatly.

> LST 1: My perception relating to STEM initiatives for instruction is that mathematics and science are conceptual, but they provide learners with understanding to a certain extent which needs to be topped up with the integration of engineering design and technological knowledge. STEM initiatives should be something that ensures that learners are equipped with conceptual and practical knowledge.

> LST 2: I believe that STEM initiatives are programs that could immensely benefit learners both theoretically and practically, particularly if they would engage learners more in problem-solving yet require them to apply two or more discipline knowledge at a time to conclude a model\project. In this manner, they are equipped with a set of skills.


LIFE SCIENCES LESSON PLAN

Teacher's name:

Classes:

Theme: Life processes in plants and animals

Topic: Plant responses to the environment

Grade: 12

Lesson outcomes:

1. Plant growth substances
   - Auxin, Gibberellins & Abscisic acid
2. Types of tropism
   - Phototropism & Geotropism
3. Role of auxin in phototropism
4. Role of auxin in geotropism

Activities: 4 Homework: 2 Classwork: 2

Teacher:

D.H.:

Figure 7. LST 2's lesson plan (Source: Authors' own elaboration)

Figure 8. LST 2's project designed by learners (Source: Authors' own elaboration)

> LST 3: STEM initiatives are essential because they would develop learners mentally to succeed in any field of their choice. Also, these initiatives could require learners to be more practical, to challenge them to think critically with the goal of coming up with solutions to real-world problems.

LST 2's lesson plan was well-constructed, and the objectives were well-constructed (**Figure 7**). However, the teacher did not have any materials to teach the topic, such as a plant to show various structures of the plant and how the plant responds to environmental stimuli.

Figure 8 shows a project a learner designed to demonstrate how a double-stranded DNA molecule looked like and how nitrogenous bases paired with each other in a DNA molecule.

Sub-theme 2: Preparation of STEM classrooms

The environment should be set up in a manner that caters for effective and successful learning of STEM disciplines. All three teachers were asked how the STEM classroom and school environment should be prepared to be stimulating. The following were their responses to the question.

Diversity-accommodating environment:

> LST 1: Preparation of STEM classrooms should be in a manner that caters for all learners in terms of various learning styles.

The teacher lacks the knowledge of how the STEM education environment should be prepared in terms of how the set-up should be in the classroom in terms of activities or the conduction of the teaching and learning process. They understood the aspects that should be looked at when delivering the content, that is, STEM-based, together with the types of activities that should be included, but he did not mention how learners should be seated in a STEM classroom and the materials that should be present to induce STEM activities, as well as the overall presentation of the classroom set up. It was observed that learners were seated individually in the classroom and did not help each other in any way. As a matter of fact, the teacher instructed learners not to help each other tackle questions that he posed to them, despite group\teamwork being crucial in STEM classrooms.

> LST 2: I think a conducive environment is key for proper instruction of STEM education. An environment that allows diversity of learning in one classroom.

The two teachers' understanding of how STEM stimulating environment should be prepared was the same. Like LST 1, LST 2 also made mention of the teaching and learning aspects of STEM but not of how the whole classroom set-up should be in terms of preparing for a STEM education conducive environment. It was noted by the researcher that the teacher had more than 40 learners in his class, which made it impossible for groups to be formed for learners to help each other to brainstorm various solutions to the problems posed by the teacher. Instead, learners talked directly with the teacher regarding solutions to problems, which teachers declined or accepted on the spot as they were seated individually.

> LST 3: For me, I think well-prepared STEM classrooms constitute diversity whereby diverse learners are allowed to learn STEM concepts differently according to their different cognitive levels with the teacher scaffolding them here and there.

Practical aspect of STEM classroom preparation:

> LST 1: STEM classrooms should be prepared in terms of practical activities with the surrounding environment full of carious charts from each topic together with materials that will enable learners to successfully carry out designs.

> LST 2: STEM classroom should mostly consist of models that learners can use to familiarize themselves with some structures like how and where lungs are situated, models that help them learn easier so that it becomes easier for them to design their own projects knowing exactly how certain structures actually looks like.

> LST 3: First and foremost, learners need to engage heavily in practical activities in the laboratory where they are able to make mistakes and rectify them at the same time. In this way, learners are taught to be independent citizens who are fully equipped with the 21st century skills.

DISCUSSION

The discussion is divided into five sections based on the study results.

Understanding STEM Education

The study highlights a significant challenge with the comprehension of the basic tenets of STEM education after what the abbreviation stands for among teachers. Responses provided by LST 1 and LST 3 revealed a superficial understanding of what STEM education entails. They merely gave the components of acronym–science, technology, engineering, and mathematics. The lack of comprehension concurs with Bybee (2013) and Mafugu et al. (2022), who pointed out numerous challenges linked to STEM education, and Giamellaro and Siegel's (2018) study underscores the absence of a distinct and well-defined academic identity for STEM. The lack of depth in understanding also aligns with findings by Mansour and El-Deghaidy (2015) who noted the implication of inadequate pedagogical knowledge among teachers as hindering the seamless integration of STEM Education in classrooms. The need for robust professional development aimed at deepening teachers' understanding of the implementation of STEM education in a way which fosters critical thinking and real-world problem solving among students cannot be overemphasized.

The Role of Constructivism in STEM

The application of constructivist learning theory in STEM education was a central theme in this study, reflecting the importance of active, hands-on learning in promoting a deep approach to learning. Constructivism, as outlined by Fosnot (2005) and Bada and Olusegun

(2015), positions learners as active participants in their learning, building knowledge through experiences and social interactions. In the context of STEM, this approach is crucial as it encourages students to engage with real-world tasks, thereby making abstract concepts more tangible. The study's observations, particularly the use of models in teaching by LST 1, demonstrate an attempt to apply constructivist principles, though the teacher-centered approach limited the potential benefits. The seating arrangement for LST 1 and LST 2 as detailed in the next paragraph also provides opportunity for the constructivist approach. This underscores the need for further training to help teachers fully embrace constructivist strategies in their STEM instruction.

The seating arrangements for the classes of two of the participants reflected that learners could discuss some of the issues because learners were sitting in pairs. This provided opportunities for utilization of constructivist approaches by LST1 and LST2 although the study observed this lost opportunity. Learners were encouraged to take responsibility for their learning by connecting new knowledge to their existing knowledge and experiences (Dennick, 2016) only through the connection to previous knowledge during introductions, but they are given only individual work. The lesson plans were not detailed and did not indicate the possibility of group activities in class. However, in the class for LST 3, learners sat individually, making it difficult to engage in discussion. Additionally, the issue of discussion was hindered by overcrowding in the class which made it difficult for learners to work in groups without disturbing other members of the groups. The barriers to group work compromised the process of utilizing constructivist-aligned learner-centered cooperative learning. Sevda and Sevim (2018) highlighted that it fosters the learner-centered approach, which promotes critical thinking. However, the use of models, and project-based activities facilitated in class, was critical as it enhanced the development of problem-solving skills. The models, although not highlighted in LST 1 's lesson plan, were in the observed but overcrowded class. Models according to (Khotimah et al., 2021) offer the learners the opportunity to use knowledge from different disciplines.

Resource Availability and Its Influence

The availability of resources is a determining factor in the effective implementation of STEM education, as highlighted by the findings of this study. The schools in the study were not well-equipped with teaching aids, laboratory facilities, and digital tools to provide an environment conducive to hands-on learning, which is central to STEM education. Learners in the classroom in LST 1 were observing the model from a distance, not in life sciences laboratory. This aligns with the observations made by Timms et al. (2018), who argue that resource-rich environments enable teachers to deliver more engaging and interactive lessons, thereby enhancing student outcomes in STEM subjects. On the other hand, the challenges faced by teachers in resource-limited settings (like in this study) point to a broader issue of educational inequality. The disparity in resource availability not only affects the quality of STEM education but also exacerbates the existing achievement gap among learners from different socioeconomic backgrounds. Addressing this issue requires targeted interventions, such as increased funding for under-resourced schools and the provision of essential STEM materials, to ensure that all students have equal opportunities to engage with and benefit from STEM education.

Challenges in Classroom Readiness

The study also explored the readiness of classrooms to support STEM education, revealing significant gaps in both physical resources and instructional strategies. Teachers struggled with overcrowded classrooms and limited access to diverse instructional materials, which hindered their ability to create an inclusive and engaging learning environment. This is consistent with the findings of Timms et al. (2018), who highlighted the imbalances in the current STEM curriculum and the challenges these pose to both learners and teachers. The lack of adequate preparation and resources in STEM classrooms not only limits the effectiveness of STEM education but also demotivates both students and teachers, further exacerbating the skills shortage in critical fields as noted by Charette (2013).

Integrative Approaches to STEM

Despite these challenges, the study acknowledges the importance of interdisciplinary and integrative approaches to STEM education. Thibaut et al. (2018) argue that effective STEM education requires the integration of multiple disciplines to address real-world problems comprehensively. The study observed that while teachers attempted to incorporate various STEM subjects, the lack of a clear understanding of integration often led to fragmented instruction rather than a cohesive learning experience. Giamellaro and Siegel (2018), who stress the necessity of a clearly defined academic identity for STEM education to allow successful integration into classroom practices, corroborate this observation. In order to close this gap, a concerted effort must be made to define the objectives of STEM education and give educators the resources and training they need to successfully apply integrative methods.

Implications for the Study

This study emphasizes the crucial need for practical implications in the realm of teacher professional development. The research highlights the significant role that higher education training institutions play in equipping educators with the necessary skills and knowledge. By providing ample opportunities for continuous learning and professional growth, these institutions can help teachers enhance their ability to effectively implement integrated STEM (Science, Technology, Engineering, and Mathematics) education in their classrooms.

Integrated STEM education is essential in fostering a holistic understanding of these interconnected disciplines, and it requires educators to be proficient not only in content knowledge but also in pedagogical strategies that promote interdisciplinary learning. Training programs must therefore focus on practical, hands-on experiences that allow teachers to experiment with and refine their instructional techniques.

Furthermore, the study underscores the importance of creating supportive learning environments where educators can collaborate, share best practices, and receive constructive feedback. By addressing these professional development needs, educators will be better equipped to design and deliver engaging, innovative lessons that captivate students' interests and motivate them to explore STEM fields more deeply.

Through well-structured professional development programs, teachers can develop the confidence and competence needed to integrate technology, engineering challenges, and scientific inquiry into their daily teaching practices. This approach not only enhances students' critical thinking and problem-solving skills but also prepares them for future academic and career pursuits in STEM-related areas.

In conclusion, by investing in comprehensive professional development for teachers, higher education institutions can significantly contribute to the quality of STEM education. This investment will ultimately lead to the creation of more engaging and stimulating learning experiences, fostering a deeper understanding and appreciation of STEM concepts among students, and preparing the next generation for the demands of a rapidly evolving technological world.

The study's results, based on only three schools, may not accurately represent broader populations, such as schools in different regions, with varying sizes or demographics. This limitation affects the ability to generalize the findings to other contexts. Depending on how the schools were selected, there could be unintended biases–such as regional, economic, or performance-related factors–that might have influenced the results. For example, if the chosen schools are located in a particular economic region or have a similar student body performance level, the findings might not apply to schools with different characteristics. Procedurally, this study suggests a need for follow-up research with larger, more randomized, and diverse samples to determine whether the results are consistent across various contexts. Methodologically, a broader study design would help enhance the external validity and generalizability of future research.

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