Science Teachers' Instructional Practices: A Need Analysis for Preparing Integrated STEM Practices through Scientist-Teacher-Student Partnership

Mohamad Hisyam Ismail[1*], Hidayah Mohd Fadzil [2*], Muhamad Furkan Mat Salleh[3], Rohaida Mohd Saat[4], Cepi Kurniawan[5], Eko Hariyono[6]

[1 3]Science Education Department, Faculty of Education, Universiti Teknologi MARA, Puncak Alam Campus, Selangor, Malaysia
hisyam_ismail@uitm.edu.my
[2 4]Department of Mathematics and Science Education, Faculty of Education, University of Malaya, Kuala Lumpur, Malaysia
hidayahfadzil@um.edu.com
rohaida@um.edu.my
[5]Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia
kurniawan.cepi@mail.unnes.ac.id
[6]Department of Physics, Universitas Negeri Surabaya, Indonesia
ekohariyono@unesa.ac.id
[*]Corresponding Author

https://doi.org/10.24191/ajue.v20i3.27858

Received: 7 June 2024
Accepted: 10 September 2024
Date Published Online: 28 October 20204
Published: 28 October 20204

Abstract: The declining number of students choosing STEM subjects and careers in Malaysia has raised concern about the education system's ability to produce sufficient human development for sound national development. The teaching approach used by the teachers to integrate STEM in the classroom practices is often claimed as one of the main determining factors contributing to this issue. Concerning this issue, this qualitative study aimed to investigate science teachers' practices in integrating STEM in their classrooms. The interviews were conducted with six science teachers from various secondary schools in Malaysia who represented three major disciplines (Biology, Physics, and Chemistry). The purposive sampling technique was employed to select six science teachers who were involved in this study. As part of a larger study, the objectives of this study were mainly focused on exploring the instructional practices by the teachers to integrate STEM content in their classrooms, where constant comparative methods were used for data analysis. Three themes emerged from the interviews, namely, (1) instructional strategy, (2) elements of STEM, and (3) issues of the practice. The study found that all science teachers have different strategies to integrate STEM into their classrooms, such as inquiry-based and problem-based learning. To integrate STEM disciplines, the teachers are mostly focused on embedding STEM skills through hands-on activity or highlighting the real-life applications of the STEM concepts during the lesson. Less emphasis is given on connecting concepts of different disciplines during teaching and learning, and teacher-driven activities were among the issues discovered in teachers' instructional practices. Despite their efforts, they admitted that they still lack the skills to integrate STEM and need help from experts, mainly from STEM practitioners like scientists and engineers. The study concludes that science teachers need to improve their delivery of STEM subjects more effectively. Moreover, the findings could assist stakeholders, particularly teacher training institutions, in re-assessing their education programs for current demand.

Keywords: Integrated STEM, Instructional practices, Scientist-teacher-student partnership (STSP), Science teacher, Teaching and learning

1. Introduction

Teaching science in-silo and as a single disciplinary subject with minimal connection with real-life applications creates a fragmented and lack of meaning in students' learning experience. To overcome the shortcomings, the current education context is shifting its attention to integrated STEM education, emphasising the importance of applying equal attention to two or more STEM disciplines or explicitly assimilating concepts from different STEM disciplines while implementing instructional practices (Abramowitz et al., 2024; Stump et al., 2016). This is because the integration of STEM disciplines provides opportunities for 'more relevant, less fragmented, and more stimulating experiences for learners' (Furner & Kumar, 2007), reflecting the real-world problems and not as an isolated issue on a specific discipline as what students have been taught in schools (Pearson, 2017). Besides, it allows students to practise critical thinking and problem-solving and seeks knowledge and ideas through the flexible learning experience. Past studies also concurred that the integrated STEM approach empowers students to acquire social skills, communication skills, scientific thinking, self-control, and adaptation to innovation and creativity (Bybee, 2010; NRC, 2012; Vansdadiya et al., 2023).

Henceforth, mastering STEM-related subjects is deemed as a potential mechanism to shape the future generation in facing global and future challenges due to technological progression and industrial revolutions (Saat et al., 2022; Salleh et al., 2020; Shahali et al., 2019). In the Malaysian Education Blueprint 2013-2025, the Malaysian government, through the Ministry of Education (MOE), is moving towards this direction by positioning STEM Education as one of the critical agendas in transforming the Malaysian education system (MOE, 2014). Besides, the nation's economic future also hinges on the sufficiency of STEM graduates and professionals. Based on the New Economic Model (NEM) projection, Malaysia aims to create 1.3 million jobs in various STEM disciplines by 2025 to ensure the continuous progression of industrial clusters. However, the Ministry of Science, Technology, and Innovation (MOSTI) is concerned about the current ratio of STEM to non-STEM students at the secondary level where based on the Education Ministry's 2020 Annual Report, the percentage of STEM students is only 47.18 per cent where 20.51 per cent is in pure science stream while remaining 26.67 percent is in Technical and Vocational Education and Training (TVET). On top of that, MOE has also identified the 'worrying trend' where there is an approximately 15 percent increase in the number of students who have met and passed the requirement to enrol in science stream classes at upper secondary schools; however, they chose not to do so. In the long run, this phenomenon will undoubtedly threaten the growth of Malaysia's economy and talent in the near future, as STEM talents are the catalyst for the development of a country.

Concerning the issue mentioned above, many studies have been conducted to reveal the reasons why students become uninterested and unmotivated to choose science and STEM subjects (Alan et al., 2019; Christensen et al., 2014; Furner & Kumar, 2007; Garrecht et al., 2023; Swarat et al., 2012; Tytler & Osborne, 2012). Even though the students come to school with a robust intrinsic interest in science, the decline of their interest is due to the way science subjects are taught in school, especially the approach used by the teacher in class. Science teachers' incompetence (Furner & Kumar, 2007; Saat et al., 2022; Swarat et al., 2012), especially when it comes to conducting hands-on activities and experiments (Fadzil & Saat, 2013) had a negative impact on the quality of STEM learning. In another study, Martínez (2020) reported that a lack of pedagogical content knowledge in teaching science subjects is a primary factor contributing to these issues. As a result, students are unable to solve problems and exhibit a lack of creative and critical thinking abilities due to their lack of understanding of the context in which STEM-related problems exist (Furner & Kumar, 2007). Other local studies also reported teachers have insufficient opportunities to be critical, creative, and innovative because they lack the necessary STEM knowledge (Abrahams et al., 2013; Rahman et al., 2021). Almost half, i.e., 47 percent of the 16,115 secondary school STEM teachers involved in the study mentioned they had never attended any STEM-related training (Rahman et al., 2021). Although MOE has come up with initiatives to train STEM teachers, as clearly stated in Malaysian Education Blueprint 2013-2025, there might be a loophole in implementation that needs to be re-looked at (Ibrahim et al., 2024). Some studies also found that teachers struggle to integrate STEM elements into their classrooms due to a lack of content knowledge. The teachers even find it challenging to engage and encourage students to participate in their designed activities (Ismail et al., 2019; Garrecht et al., 2023; Gonzalez-DeHass et al., 2017).

Other studies also found that STEM Education is mostly taught with the theoretical approach instead of the practical approach (Bunyamin & Finley, 2016; Ismail et al., 2017; Prameswari & Budiyanto, 2017; Saat et al., 2022). Most experiments are conceptualised, physical actions are imagined, chemical reactions and biological processes are described, or perhaps the students are given videos related to the concepts for them to watch. Studies also noted that teachers conduct demonstrations and laboratory activities occasionally to verify the concepts taught in the classroom and drill students with exercises to make them familiar with examination questions (Bunyamin & Finley, 2016; Ismail et al., 2017; Prameswari & Budiyanto, 2017; Tay & Saleh, 2019; Saleh & Yakob, 2014). Besides that, students do not acquire important skills and are not given appropriate exposure due to the 'ill practice' of spoon-feeding the students, which is practised by teachers (Ismail et al., 2015; Mafarja et al., 2023). They are also frequently instructed to memorise concepts that are difficult to comprehend or to copy solutions to challenging problems without being encouraged to solve them. Even faced with many criticisms of such practices, teachers often mention time constraints as the main 'culprit' for teachers to limit students' avenues to develop their critical thinking through concepts and problem exploration (Salleh et al., 2020). Apart from that, 'chasing syllabus syndrome' due to the examination-oriented culture embraced by the system has diminished the time for teachers to spend on STEM instructional practices, which could give meaning to students' knowledge (Goh & Matthews, 2011).

Engaging students with inquiry-based learning, project, and problem-based learning through STEM instructional practices is one of the contemporary pedagogical activities that sustains the interest of students in learning science and promotes more holistic science learning with a more experiential and authentic context. These instructional strategies place students' ideas, questions, and observations at the centre of the learning experience, which requires them to engage in evidence-based learning and creative problem-solving. These strategies also promote active learning, engagement of students throughout the process of learning and higher-order thinking (Khattak, 2017; Savery, 2015). However, in a specific study that focuses on the local context in secondary school, the instructional practices have an insignificant level of interaction, whereby the teachers did most of the talking and instructing while only a small number of students contributed their views. Most teachers are still at ease adapting teacher-driven activities that deprive students of opportunities to be more innovative, creative, and critical due to a lack of STEM integration skills in their science classrooms (Ismail et al., 2017). Besides that, even though science teachers mostly are trying to practise the student-centred teaching approach, they still dominate their classrooms (Saleh & Liew, 2018). Changing instructional practices to be more student-driven is already challenging, given that it is not simply a straightforward process. Not to mention, delivering a single discipline science subject in a more integrated manner – incorporating concepts or knowledge from multiple STEM disciplines – will undoubtedly increase the instructional challenge and put teachers' capacity to design effective instructional practices to the test. Thus, teacher training institutions, particularly universities with education programs, must ensure that their program designs are effective and responsive to current demands, especially in the context of the 21st century and the upcoming Industrial Revolution 5.0.

Collaboration or partnership among the community of practice and science teachers has become one of the effective strategies for reforming science education as mentioned by the literature (Abramowitz et al., 2024; Adams & Hemingway, 2014; Houseal et al., 2014; Shein & Tsai, 2015). Integrated STEM instructional practices may not be effective if there is no strategic partnership for the process of designing and implementing the lesson (Ufnar & Shepherd, 2019). This is the main reason the researcher conducted a need analysis study. The findings can help science teachers in their instructional practices by involving the community of practice experts in the STEM field. In this study, 'Scientist-Teacher-Student Partnership', (STSP) refers to a collaboration between three parties which are university scientists, secondary science teachers and secondary science students through a partnership for the benefit of STEM learning. Many studies have reported that partnerships involving the community of practice benefit all groups educationally (Abramowitz et al., 2024; Saat et al., 2022). For science teachers, this partnership provides education to teachers about the scientific inquiry process, broadens their content knowledge and pedagogical strategies, and revitalises their teaching (Saat et al., 2022; Tanner, 2003; Ufnar & Shepherd, 2019). For scientists, the partnership improves their communication and pedagogical skills, while science students get benefits through authentic interaction and learning with the scientific community and also improving their content knowledge and STEM skills where it also improves their science performance (Tanner, 2003). Moreover, the partnership between educational institutions and community of practice was proven effective in enhancing STEM education because numerous countries had invested their educational funds and efforts in establishing this partnership (Burnett, 2010).

To integrate STEM during science lessons, science teachers must be equipped with sufficient content knowledge and skills related to pedagogical content knowledge. Therefore, having a conceptual framework for integrated STEM Education is really important (see Figure 1). Through the framework, integrating STEM not only focuses on teaching content and skills but also guides and facilitates students in making connections to real-world applications. The concern is more on connections between the four STEM disciplines and provides a relevant context for learning the content. Besides, the framework involves components of situated learning, engineering design, scientific inquiry, technological literacy, and mathematical thinking and is bounded by the rope of community of practice that works as an integrated system. Through the frameworks, it shows the important role played by the 'community of practice' or STEM experts in order to move the whole system.

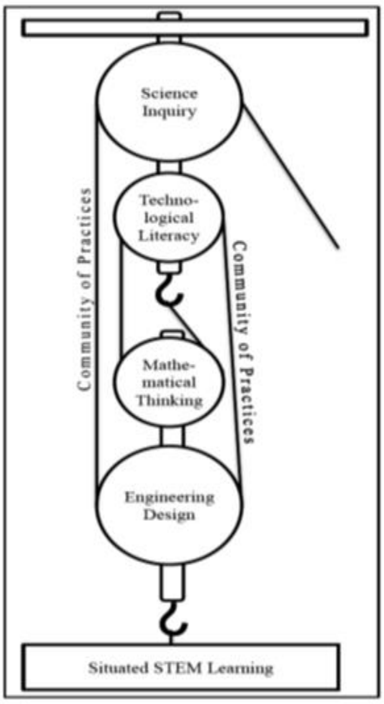

Fig. 1 A conceptual framework for the ideal integrated STEM approach proposed by Kelley & Knowles (2016).

With a similar intention, this paper discusses the need analysis study, which was conducted by the researcher prior to proceeding with the scientist-teacher-students partnership (STSP) initiative to develop integrated STEM instructional practices. To identify the needs of science teachers, the researcher had explored their instructional practices to integrate STEM in the three science disciplines, namely Biology, Physics, and Chemistry, in one secondary school. This study focused on answering the following research question: How did science teachers (Biology, Physics and Chemistry) integrate STEM in their instructional practices?

2. Methodology

To explore science teachers' instructional practices, the researchers adopted the basic interpretive study under the qualitative research design. This approach is appropriate for acquiring rich data and information to answer the research question of how science teachers integrate STEM into their lessons. Moreover, qualitative research allows the informants to use their own words to 'make sense of their lives and 'place importance on context and process' (Kelley & Knowles, 2016). Thus, exploring participants' responses regarding their instructional practices is believed to be the most suitable technique to use. Besides, employing basic interpretive qualitative study provides the researchers with a real-life phenomenon with an abundance of holistic, thick, and rich descriptions that can ultimately lead to future research (Merriam & Tisdell, 2015). Therefore, teachers' experiences in the classrooms, their strategies in teaching, and how they approach and make sense of the phenomena under study can only be explored by using qualitative inquiry. Additionally, the basic interpretive qualitative study has proven particularly useful for studying research in the educational context and instructional practices by "drawing upon concepts, models, and theories" (Merriam & Tisdell, 2015).

In this study, the researcher used purposive sampling (King, 1991) to select the participants involved in the data collection process. The participants were six science teachers who teach physics, chemistry, and biology in three different secondary schools in Selangor. The main criterion for choosing the participants was mainly due to their teaching experience, where only teachers who have experience teaching science subjects (physics, chemistry, and biology) for more than five years were selected to become participants. This is important to make sure that the participants are considered to have enough experience in their own field and would be 'knowledgeable informants' (Guba & Lincoln, 1994). Besides, five years of experience in the teaching field can be considered an expert. Therefore, the teachers can provide much information to the researcher. This study's primary data source was verbal data collected via semi-structured interviews. The interview structure enabled researchers to react to participants' responses throughout the session, for example, by probing for clarification for an in-depth understanding of the participants' emerging responses (Merriam & Tisdell, 2015). The interview adhered to a set of interview protocols that had been peer-reviewed and validated (refer to Table 1). The interviews were conducted one-on-one, according to the time preferences of the participants. The researcher designated a specific time for participants to choose. The interview process took two weeks in total with the six participants.

The entire interview process was audio-recorded. For data analysis, the researchers employed the constant comparative method (Merriam & Tisdell, 2015). All recordings were transcribed verbatim. After familiarising with the transcribed data, the researchers read the transcripts multiple times, then chunked and coded the data. The emerging codes were used to generate categories and themes. Data collection and analysis were conducted iteratively until data saturation was reached (King, 1991). Given the critical importance of validity and reliability in the data analysis process, investigator triangulation was implemented. Multiple researchers independently coded the data and compared interpretations to mitigate individual bias, thereby enhancing the credibility and trustworthiness of the themes (Creswell & Poth, 2018). Cross-validation among researchers further strengthened data validity by ensuring that the themes accurately represented the participants' perspectives. Additionally, consistent agreement among researchers during the triangulation process reinforced the reliability of the coding framework, minimising subjectivity and contributing to a more rigorous and transparent analysis (Nowell et al., 2017). This approach significantly improved the overall credibility and trustworthiness of the qualitative research data.

Table 1. Interview protocol

Number	Questions
1	Could you recall the teaching strategies you used to integrate STEM during science lessons? Why did you choose those strategies? Could you please explain?
2	What do you understand about the concept of integrated STEM? Could you elaborate more on the integrated STEM component you mentioned?
3	Have you heard about the connecting concepts in STEM? In your opinion, how can this connecting concept technique be implemented? Have you experienced using this technique during your science lesson?
4	What issues have you encountered while integrating STEM while teaching science? Are there any other challenges that you want to highlight?
5	How about conducting STEM activities with the students? How do you handle the situations? Do you manage to control your students? Could you share the techniques you have used while conducting STEM activities with me?
6	Do you think the approaches and teaching strategies that you used are the best approaches and strategies?
7	Are you satisfied with your current knowledge and skills to integrate STEM into your science lesson? Could you elaborate more? (Let the participants explain a specific situation/example)
8	Do you want to highlight any suggestions for improving our STEM education?

3. Results and Discussion

From the analysis, the researchers noted that all science teachers claimed that they have various strategies to integrate STEM into their classrooms. Based on the analysis conducted on their responses, three themes had emerged with regard to their instructional practices which are (1) instructional strategy, (2) elements of STEM, and (3) issues of the practice. The subsequent sub-headings describe the themes more extensively:

a. Instructional strategy

This theme reflects the teaching strategies used by science teachers to integrate STEM during their teaching and learning. Based on the participants' instructional strategies, they highlighted that inquiry and problem-based learning are the most effective strategies to integrate STEM in their lessons. These instructtional strategies mostly use hands-on activities and discuss real-world problems. Thus, it helps students to acquire STEM skills based on what they have experienced during the lesson. The following excerpts were taken from the interview session with the science teachers.

> As suggested, inquiry and problem-based learning are the most effective strategies for developing students' STEM skills. I even use hands-on activities with them. This is important to make sure they have real experience rather than only focusing on the theories.
>
> (P1, ln. 23-24)

> …and for the Physics lesson, I will make sure there are hands-on activities and the discussion on real-world problems to be discussed with my students. They must understand theories that they learned with the problems that I brought into the class. This type of problem-based learning is the most effective strategy to help students to acquire STEM skills.
>
> (P2, ln. 36-38)

> …hands-on activity like performing experiments and doing STEM projects during my biology lesson. These hands-on activities can shape students to become more skilful and STEM literate through their meaningful learning experience.
>
> (P3, ln. 28-29)

> IBSE (Inquiry-Based Science Education) technique as suggested by the ministry and problem-based learning. There are many real problems in chemistry that we can bring into our lesson to discuss with students. We can use that problem at the beginning of the class and ask students to find information and propose any activities or projects to solve the problems.
>
> (P4, ln. 31-33)

> …and I also encourage my students to experience hands-on activities based on the problems given. I will determine suggested STEM projects to be done and they must do the activities together with their friends. Besides, they must present the findings and the discussion take place during the presentation.
>
> (P5, ln. 39-41)

> The suggested activities in the textbooks are somehow minimal and not so effective. That's why I usually ask my students to come out with STEM projects. These hands-on activities will help them to have STEM skills, and also, they will understand the concept of integrating STEM disciplines during science classroom.
>
> (P6, ln. 25-27)

Based on the responses given, inquiry-based and problem-based learning that utilise hands-on activities and real-world problems are the instructional strategies used to integrate STEM in their science lessons. These instructional strategies are believed to be important since all participants highlighted the same strategy. The researcher even asked further why they choose to use these strategies, and the following excerpts show their explanation.

> like what I have mentioned, hands-on activities based on real-world problems really help students understand the theory they learned. They also apply the theory and concepts they learned while doing the hands-on activities. As STEM involves four different disciplines, students will become more critical and have meaningful experiences by integrating these disciplines while conducting the activities.
>
> (P2, ln. 42-44)

> By doing hands-on activities or STEM projects in class, students will become more energetic, use their critical thinking and even good for their learning experiences. But again, we as teachers need to determine the suitable STEM activities to be given to the students.
>
> (P5, ln 46-47)

Inquiry-based learning is believed to stimulate students' curiosity, which leads to instinct and desire to investigate to find an answer or solution to a problem. On the other hand, problem-based learning is also considered an essential instructional practice because students will solve problems by using their skills and knowledge through collaborative or individual work. These instructional strategies usually involve authentic hands-on projects or activities either in an ordered task, construction, or investigation that aims to achieve specific goals. Moreover, it consists in integrating multiple disciplines across the curriculum, student-centred, and linking what's learned with real life. Thus, the learning is more meaningful to the students (Lou et al., 2011; Mafarja et al., 2023; Saat et al., 2022). Besides that, hands-on activities that focus on real problems also provide a positive classroom environment, contributing to the significant factor related to attitude toward school science (Kagan, 1992; Ruby, 2001). Another study reported a significant improvement among students who participated in hands-on learning regarding their achievement, successful completion of science courses, and desire to pursue STEM degrees (VanMeter-Adams et al., 2014).

Therefore, instructional strategies for science subjects need to be appropriately planned (Ebenezer & Zoller, 1993; Karpudewan et al., 2023; Mafarja et al., 2023; Sundberg & Moncada, 1994) because science is a unique subject that involves learning scientific ideas and engaging in inquiry practices through hands-on and practical activities. Using instructional strategies with the essential elements of active learning will help increase students' interest in STEM (Mafarja et al., 2023).

b. Element of STEM

This theme reflects the science teachers' understanding of the concept of integrated STEM and the application of STEM concepts while implementing their instructional practices. Most of the participants focus on integrating four STEM disciplines (Science, Technology, Engineering, and Mathematics) in their lesson, as illustrated in the following excerpts.

> Integrated STEM is an effort to combine these four elements (Science, Technology, Engineering, and Mathematics) in a lesson. To integrate STEM in my lesson, I will make sure these four elements are presents in the instructional practices.
>
> (P1, ln. 67-68)

> It is an approach to integrate these four disciplines. To have STEM integration, I will make sure that I use technologies, have the engineering design process while conducting activities, and involve mathematical thinking and calculation.
>
> (P2, ln. 72-73)

> It is a multidisciplinary technique where the teachers integrate these four components in a single lesson. In my lesson plan, I will design my lesson creatively, including the activities to be conducted with the students that involve all these four disciplines.
>
> (P3, ln. 62-63)

In addition, the researcher further asked about the specific connecting concepts between the three disciplines of science subjects, whether the teachers emphasise the concepts in their STEM instructional practices or not. Most of their responses showed that they are not emphasising these connecting concepts, because some of them are not aware of it, as illustrated by the following excerpts.

> As far as I am concerned, the most crucial technique is to integrate between these four STEM disciplines. Science discipline is referring to the content and syllabus of science that I am going to teach. Do I need to connect concepts with the other three science disciplines?
>
> (P2, ln. 76-77)

> Since I am teaching Biology, I am more focusing on the syllabus of Biology. Some topics are related to the concepts taught in Physics and Chemistry, but if I am more focusing on this connecting concept, it will take more time, and I don't think it is practical to be done.
>
> (P3, ln. 68-69)

> Sometimes, I do highlight the connecting concepts with other science disciplines. It is good because we show to the students the connecting science concepts between Physics, Chemistry, and Biology. However, it might be time-consuming for me because to have STEM integration; I need to plan student-centred activities for my students. These activities are already taking a lot of time.
>
> (P4, ln. 64-66)

> … as I think it is good to do connecting concepts between three sciences syllabi. But, I am not having any exposure, idea, or even training related to STEM integration. That's why I am not doing that in my lesson. What currently I'm doing is to integrate these four components of STEM through the science lesson for the benefit of my students. But then, sometimes, I also ask myself either the way on what I am currently doing is the right way to integrate STEM or not.
> (P6, ln. 71-73)

Many studies have reported connecting concepts and contents through science syllabi for integrated STEM learning (Kelley & Knowles, 2016; Mafarja et al., 2023; Saat et al., 2022). This technique is believed to make learning science more relevant in authentic situations. This technique also encourages scientific inquiry and curiosity, openness to new ideas, and scepticism that characterise science. Moreover, connecting concepts through science syllabi could also influence students' interests in learning science. On the other hand, many studies have proven that STEM integration offers students the best approaches to connect learners' prior knowledge with a real-world situation, making the connection between science concepts and STEM disciplines, rather than learning bits and pieces (McComas, 2014; Saat et al., 2022; Yamin et al, 2017). Besides, it can make learning more meaningful (Mafarja et al., 2023; Wang et al., 2011).

c. Issues of the practice

This theme explains issues science teachers face when integrating STEM into science lessons. Based on the participants' responses, it was found that the implementation of activities is still heavily focused on teacher-driven rather than student-driven activities. The following excerpts show their explanations.

> I have to plan for the specific STEM activities before I go to my class. Besides, I have to make sure that all STEM elements are present and integrated. Usually, the students were just doing what I have planned; thus, it is more structured and manageable for me.
> (P1, ln 104-105)

> …as mentioned, I will prepare the framework of the STEM activities. I will make sure every student involves and do the tasks that I have prepared. It is more practical and easier to control than asking them to come out with their own activities based on the real problem we discussed.
> (P4, ln. 117-119)

> Since most activities involve group work and the students have to collaborate among them thus, I have to prepare the STEM projects for them. If I ask them to design any STEM activities, usually it takes so much time based on my previous experience. To speed up the time, I prepared everything, and the students are just doing the project.
> (P5, ln. 109-111)

> The STEM activities or projects are quite challenging for the students. Therefore, usually, I will guide them to find the answer to the problems that we are discussing in class. Sometimes, I have to give solutions and let them find the reason based on my answer. This is the fastest way to make sure we can finish the activities in the stipulated time.
> (P6, ln. 125-127)

Based on the participants' responses, most of them still heavily focus on teacher-driven activities. They sometimes underestimate their students and do not give their students chances to design the activities or explore ideas and solutions for problems or tasks assigned. Salleh et. al. (2022) highlighted the importance of recognizing students' potential and practice equitable learning approach to maximise students' potential. Moreover, this could hinder the outcomes of STEM learning to be achieved by the students because studies reported that student-driven activities through integrated STEM lessons provide students with the experience of engineering design and technological knowledge and become STEM literate are capable of dealing with complex problems (Mafarja et al., 2023; Park et al., 2015; Plangwatthana, 2013). However, if more teacher-driven activities are used in the science lesson, students might be unable to adapt their critical thinking and problem-solving skills (Frykholm & Glasson, 2005; Mafarja et al., 2023). Moreover, it can impose students' perceptions of STEM-related subjects as stable, rigid, fixed, and a narrow platform for developing and constructing desirable identities (Claudio, 2001; Holmegaard, 2014). Some students have thought integrated STEM lessons are not innovative or creative (Shahali et al., 2019). As learners fail to value and make connections between their prior knowledge, they cannot make connections between science disciplines and skills that they have learned through the subject. Thus, the learning is not meaningful (Gasiewski et al., 2012; Mafarja et al., 2023; Fadzil & Saat, 2013).

Apart from that, the participants also highlighted they require training and exposure due to the lack of skill to integrate STEM in their instructional practice during teaching Science lessons.

> I only have five years left before I retire. Since the new curriculum requires the teacher to integrate STEM in science lessons, thus I have to do that. The specific training and workshop on STEM teaching need to be given since until now, I don't think we have a clear framework on STEM education.
>
> (P1, ln. 141-142)

> Specific training and teacher guidance need to be prepared. If you look at the DSKP, they (MOE) mention the need to use the STEM approach in teaching science. However, they don't give any clear guidance and training to the teachers. Usually, I need to explore how to come out with science instructional practice that integrates STEM components on my own.
>
> (P3, ln. 132-134)

> When school plan for the CPD (continuous professional development) training, they have to decide on specific training and workshops on STEM teaching. It should be done in a practical way. Not just explaining and giving theories that we can read on our own. We need to upgrade our STEM skills, and we want more in terms of the latest exposure to the STEM teaching.
>
> (P5, ln. 152-154)

> We want a specific STEM-pedagogical approach training. Because what we are doing now is based on what we understand. But then, like what I have mentioned just now, I also sometimes doesn't sure either what I am doing is the right way to integrate STEM or not. However, the students enjoyed the class, and I noticed they learned something new through the science lesson using an integrated STEM approach.
>
> (P6, ln. 162-164)

The participants mentioned that they need help from experts, especially STEM practitioners, to guide and share expertise in designing effective integrated STEM instructional practices that can be executed during science lessons. The findings align with other studies that revealed the demand for collaboration with industries or experts to expose science teachers to effective STEM activities or programs (Mafarja et al., 2023; Yahya et al., 2015). The following excerpts show what they highlighted.

> I think it is good if the school involves experts like scientists and engineers in helping us to design the effective integrated STEM instructional practice. As they are experts in their world, thus they also can help to bring real-world problems and situations into the classroom.
>
> (P1, ln. 158-159)

> Specific guidance and training should be given for science teachers. I think this is when the ministry or even school collaborates with the experts for conducting the training. We can utilise their expertise in getting ideas on the process of designing STEM lesson planning. We even can learn from these experts.
>
> (P3, ln. 147-149)

> Bring experts to school. Bring scientists, engineers, technologists, and even mathematicians to the school for CPD training. Ask teachers to work with these experts on designing science lesson that integrates STEM components. I think students will be happy and enjoy the new science lesson and even teachers will also learn something new and meaningful.
>
> (P5, ln. 174-176)

> Ministry should provide specific STEM modules for science lessons to be used by the teachers and students. To have this, the ministry needs to collaborate with the stakeholders and even experts like professors, scientists, and even engineers. Ask them about their real working experience. Bring the situations into the STEM modules. So, we will be having many genuine real problems in the modules. Then, train teachers through specific workshops on the STEM-pedagogical approach. Thus, we as teachers will have a clear picture of integrating STEM through the science lesson.
>
> (P6, ln. 182-185)

Teachers are the ones responsible for integrating STEM lesson planning, facilitating the process, and also guiding the students during science class based on what they have prepared in their lesson plan before delivering the instructional practices. Commonly, in school, teachers will leave impacts on students' interests during teaching and learning. Therefore, the teachers must have specific STEM skills and knowledge to continuously motivate and guide the students. Besides, the teachers can provide the students with the opportunity to adopt and adapt STEM knowledge and skills by facilitating them in making decisions and solving problems through tasks and activities designed in the instructional practice. The involvement of the experts or STEM practitioners is one of the common approaches for science education reform (Wormstead, 2002). The critical inputs like skills, experience, and ideas that STEM experts have are beneficial for designing the integrated STEM instructional practice. In addition, the mentorship and guidance given by the STEM experts such as scientists could also upgrade teachers' content knowledge and pedagogical skill. Hence, it could also provide a fresh perspective of the scientific inquiry process, extend teachers' pedagogical content knowledge and renew or innovate teaching practices in the science classroom (Schielke, 2014).

4. Conclusion

In conclusion, since this study was part of a more extensive study that focused on exploring the instructional practices the teachers use to integrate STEM content in their classrooms, it can be concluded that science teachers have different instructional strategies to integrate STEM into their classrooms, such as inquiry-based and problem-based learning. The teachers mainly focus on embedding STEM skills through hands-on activity and real-life applications of the STEM concepts during the lesson. However, less emphasis is given on connecting concepts of different science syllabi, and teacher-driven activities are among the issues discovered in teachers' instructional practices. The teachers also admitted that they still lack the skills to integrate STEM and need help from experts, mainly STEM practitioners, to upskill and upgrade STEM-related aspects. The involvement of experts, i.e., STEM practitioners, through a strategic partnership called scientist-teacher-student partnership (STSP) is necessary to help science teachers to improve instructional practices during science lessons. STSP could enhance teachers' skills and knowledge, such as planning and designing STEM activities in their class, besides exposing them to the strategic way to integrate STEM concepts between the STEM disciplines. This could be considered part of continuous professional development (CPD) in which teachers are allowed to interact with the community of practice (specifically scientists in this study) and grow professionally in the authentic learning environment.

The implications for teacher training institutions, especially in the university, are really significant, as it highlights the necessity for teacher training programs to adapt to the evolving educational landscape. Science curricula and learning experiences of the future science teacher should be revised to incorporate contemporary pedagogical practices that foster critical thinking, inquiry based and problem-solving skills essential for navigating the complexities of the 21st century. Additionally, the study underscores the importance of aligning educational content with real-world applications and current scientific advancements, particularly in light of the forthcoming Industrial Revolution 5.0. This calls for a shift towards more experiential learning opportunities, such as hands-on laboratories and collaborative projects with STEM practitioners, which can enhance engagement and better prepare future science teachers. Furthermore, the findings reflected the need for higher education institutions to prioritise interdisciplinary approaches that integrate STEM, thereby fostering a more holistic educational experience that reflects the interconnected nature of modern scientific inquiry.

5. Co-author Contribution

The authors affirmed that there is no conflict of interest in this article. Author 1 and Author 2 carried out the fieldwork, prepared the literature review and methodology, and overlooked the whole article's writeup. Author 3 and Author 4 carried out instrument and data validation processes, reviewed the results' interpretation, and contributed to article refinement. Author 5 and Author 6 prepared the literature review and carried out data analysis.

6. Acknowledgement

The main author of this manuscript is an academic staff of Universiti Teknologi MARA. He is currently pursuing his PhD at the University of Malaya under the UiTM-KPT SLAB scholarship scheme.

7. References

Abramowitz, B., Ennes, M., Kester, B., & Antonenko, P. (2024). Scientist-school STEM partnerships through outreach in the USA: A systematic review. *International Journal of Science and Mathematics Education*, 1-23.

Abrahams, I., Reiss, M. J., & Sharpe, R. M. (2013). The assessment of practical work in school science. *Studies in Science Education*, *49*(2), 209-251. https://doi.org/10.1080/03057267.2013.858496

Adams, C. T., & Hemingway, C. A. (2014). What does online mentorship of secondary science students look like? *BioScience*, *64*(11), 1042-1051. https://doi.org/10.1093/biosci/biu147

Alan, B., Zengin, F. K., & Keçeci, G. (2019). Using STEM applications for supporting integrated teaching knowledge of pre-service science teachers. *Journal of Baltic Science Education*, *18*(2), 158-170. https://doi.org/10.33225/jbse/19.18.158

Bunyamin, M. A. H., & Finley, F. (2016). STEM education in Malaysia: Reviewing the current physics curriculum (2nd ed.).

Burnett, N. (2010). How to develop the UNESCO the world needs: The challenges of reform. *Journal of International Cooperation in Education, 13*(2), 89-99.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30.

Christensen, R., Knezek, G., & Tyler-Wood, T. (2014). Student perceptions of science, technology, engineering and mathematics (STEM) content and careers. *Computers in Human Behavior*, *34*, 173-186. https://doi.org/10.1016/j.chb.2014.01.046

Claudio, L. (2001). Reaching out to the next generation of scientists. *Thought and Action*, *17*(1), 77-86.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). SAGE Publications.

Ebenezer, J. V., & Zoller, U. (1993). Grade 10 students' perceptions of and attitudes toward science teaching and school science. *Journal of Research in Science Teaching*, *30*(2), 175-186. https://doi.org/10.1002/tea.3660300205

Fadzil, H. M., & Saat, R. M. (2013). Phenomenographic study of students' manipulative skills during transition from primary to secondary school. *Jurnal Teknologi*, *63*(2). https://doi.org/10.11113/jt.v63.2013

Frykholm, J., & Glasson, G. (2005). Connecting science and mathematics instruction: Pedagogical context knowledge for teachers. *School Science and Mathematics*, *105*(3), 127. https://doi.org/10.1111/j.1949-8594.2005.tb18047.x

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science and Technology Education, 3*(3), 185-189. https://doi.org/10.12973/ejmste/75397

Garrecht, C., Czinczel, B., Kretschmann, M., & Reiss, M. J. (2023). 'Should we be doing it, should we not be doing it, who could be harmed?' Addressing ethical issues in science education. *Science & Education, 32*(6), 1761-1793.

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., & others. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in Higher Education, 53*(2), 229–261. https://doi.org/10.1007/s11162-011-9247-y

Goh, P. S.-C., & Matthews, B. (2011). Listening to the concerns of student teachers in Malaysia during teaching practice. *Australian Journal of Teacher Education, 36*(3), 92-103. https://doi.org/10.14221/ajte.2011v36n3.2

Gonzalez-DeHass, A. R., et al. (2017). Pre-service elementary teachers' achievement goals and their relationship to math anxiety. *Learning and Individual Differences, 60*, 40-45. https://doi.org/10.1016/j.lindif.2017.10.002

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In *Handbook of Qualitative Research* (Vol. 2, pp. 163-194).

Holmegaard, H. T., Madsen, L. M., & Ulriksen, L. (2014). To choose or not to choose science: Constructions of desirable identities among young people considering a STEM higher education programme. *International Journal of Science Education, 36*(2), 186-215. https://doi.org/10.1080/09500693.2012.749362

Houseal, A. K., Abd-El-Khalick, F., & Destefano, L. (2014). Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *Journal of Research in Science Teaching, 51*(1), 84-115. https://doi.org/10.1002/tea.21126

Ibrahim, N., Mohamed, M., Seshaiyer, P., Mohd Rasid, N., Dalim, S., Salleh, M. F. M., Ismail, M. H., & Mohd Yusoff, M. (2024). Enhancing prospective educators' readiness through multidisciplinary collaboration in STEM education: An analysis of students enrolled in science and mathematics majors at a public university in Malaysia. *Asian Journal of University Education, 20*(2), 303-315. https://doi.org/10.24191/ajue.v20i2.27000

Ismail, M. H., Syarifuddin, N. S., Salleh, M. F. M., & Abdullah, N. (2015). School-based assessment: Science teachers' issues and effect on its implementation. *Advanced Science Letters, 21*(7), 2483-2487. https://doi.org/10.1166/asl.2015.6317

Ismail, M. H., Abdullah, N., Salleh, Salleh, M. F. M., & Ismail, M. (2017). Higher order thinking skills (HOTS): Teacher training and skills in assessing science learning. *Advanced Science Letters, 23*(4), 3259-3262. https://doi.org/10.1166/asl.2017.7732

Ismail, M. H., Salleh, M. F. M., & Aris, S. R. S. (2017). Malaysian Education Plan 2013-2025: Transformation on science. *The Social Sciences, 12*(1), 79-84.

Ismail, M. H., Salleh, M. F. M., & Nasir, N. A. M. (2019). The issues and challenges in empowering STEM on science teachers in Malaysian secondary schools. *International Journal of Academic Research in Business & Social Sciences, 9*(13), 430-444. https://doi.org/10.6007/IJARBSS/v9-i13/6869

Kagan, D. M. (1992). Implication of research on teacher belief. *Educational Psychologist, 27*(1), 65-90. https://doi.org/10.1207/s15326985ep2701_6

Karpudewan, M., Krishnan, P., & Roth, W. M. (2023). What research says about the relationships between Malaysian teachers' knowledge, perceived difficulties and self-efficacy, and practicing STEM teaching in schools. *Asia-Pacific Educational Research, 32*, 353-365. https://doi.org/10.1007/s40299-022-00658-1

Kelley, T. R., & Knowles, J. K. (2016). A conceptual framework for integrated STEM. *International Journal of STEM Education*. Springer. https://doi.org/10.1186/s40594-016-0046-z

Khattak, A. H. (2017). Solution-based learning: Educating for solutions. *Khyber Medical University Journal, 9*(2), 119-120.

King, G. R. D. (1991). Creswell's appreciation of Arabian architecture. *Muqarnas, 8*, 94-102. https://doi.org/10.2307/1523157

Lou, S. J., Tsai, H. Y., & Tseng, K. H. (2011). STEM online project-based collaborative learning for female high school students. *Kaohsiung Normal University Journal*, *30*.

Mafarja, N., Mohamad, M. M., Zulnaidi, H., & Fadzil, H. M. (2023). Using reciprocal teaching to enhance academic achievement: A systematic literature review. *Heliyon, 9*(7), Article e18269. https://doi.org/10.1016/j.heliyon.2023.e18269

Martínez-Borreguero, G., González-Pérez, M. C., & Mateos, J. M. (2020). The use of stories about the history of science as a teaching strategy for integrated STEM education. *Journal of Chemical Education, 97*(1), 45-55. https://doi.org/10.1021/acs.jchemed.9b00195

McComas, W. F. (2014). STEM: Science, technology, engineering, and mathematics, in the language of science education. In *The language of science education* (pp. 102-103). Springer. https://doi.org/10.1007/978-94-6209-497-0_92

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation* (3rd ed.). John Wiley & Sons.

Ministry of Education. (2014). *Malaysia education blueprint: Annual report 2013*. Putrajaya, Malaysia: Author.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas* (pp. 1-385). National Academies Press.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1-13. https://doi.org/10.1177/1609406917733847

Park, S.-N., Kim, S.-J., & Lee, M.-Y. (2015). Effects of integrated nursing practice simulation-based training on stress, interest in learning, and problem-solving ability of nursing students. *Journal of Korean Academy of Fundamentals of Nursing, 22*(4), 424-432.
https://doi.org/10.7739/jkafn.2015.22.4.424

Pearson, G. (2017). National academies piece on integrated STEM. *The Journal of Educational Research, 110*(3), 224-226. https://doi.org/10.1080/00220671.2017.1289781

Plangwatthana, R. (2013). STEM education and instructional management in earth, astronomy and space. *IPST Magazine, 42*(185), 19-22.

Prameswari, S. J., & Budiyanto, C. (2017). The development of an effective learning environment by creating effective teaching in the classroom. *IJIE (Indonesian Journal of Informatics Education), 1*(1), 79-86. https://doi.org/10.20961/ijie.v1i1.11960

Rahman, N. A., Rosli, R., & Rambely, A. S. (2021). Validating STEM pedagogical content knowledge scale for secondary school mathematics teachers. *Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12*(14), 3666-3678.

Ruby, A. M. (2001). Hands-on science and student achievement (Publication No. 61-10, p. 3946A) [Doctoral dissertation, The RAND Graduate School].

Saat, R. M., Piaw, C. Y., & Fadzil, H. M. (2022). Creating a grounded model of performance quality of scientist-teacher-student partnership (STSP) for STEM education. *International Journal of Science and Mathematics Education*, 1-21.

Saleh, S., & Liew, S. S. (2018). Classroom pedagogy in German and Malaysian secondary school: A comparative study. *Asia Pacific Journal of Educators and Education, 33*(1), 57-73.

Saleh, S., & Yakob, N. (2014). Teachers' conceptions about physics instruction: A case study in Malaysian schools. *Australian Journal of Basic and Applied Sciences, 8*(24), 340-347. https://doi.org/10.21315/apjee2018.33.5

Salleh, M. F. M., Nasir, N. A. M., & Ismail, M. H. (2020). STEM facilitators training programme: Trainee teachers' perceptions of the impact on their personal growth as future teachers. *Asian Journal of University Education, 16*(3), 281-291. https://doi.org/10.24191/ajue.v16i3.11091

Salleh, M. F. M., Abd. Rauf, R., Mohd Saat, R., & Ismail, M. H. (2022). Novice chemistry teachers' instructional strategies in teaching mixed-ability classrooms. *Asian Journal of University Education, 18*(2), 510-525. https://doi.org/10.24191/ajue.v18i2.18066

Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. In *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows* (Vol. 9, No. 2, pp. 5-15). https://doi.org/10.2307/j.ctt6wq6fh.6

Schielke, K., Schmidt, K., & Judith, A. S. (2014). Scientists in the classroom. *ISTA Spectrum, 40*(1), 19-23.

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Mohamad Arsad, N. (2018). Students' interest towards STEM: A longitudinal study. *Research in Science & Technological Education, 37*(1), 71–89. https://doi.org/10.1080/02635143.2018.1489789

Shein, P. P., & Tsai, C.-Y. (2015). Impact of a scientist–teacher collaborative model on students, teachers, and scientists. *International Journal of Science Education, 37*(13), 2147-2169. https://doi.org/10.1080/09500693.2015.1068465

Stump, S. L., Bryan, J. A., & McConnell, T. J. (2016). Making STEM connections. *The Mathematics Teacher*, *109*(8), 576-583.

Sundberg, M. D., & Moncada, G. J. (1994). Creating effective investigative laboratories for undergraduates. *BioScience, 44*(10), 698-704. https://doi.org/10.2307/1312513

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching, 49*(4), 515-537. https://doi.org/10.1002/tea.21010

Tanner, K. D., Chatman, L., & Allen, D. (2003). Approaches to biology teaching and learning: Science teaching and learning across the school–university divide—cultivating conversations through scientist–teacher partnerships. *Cell Biology Education, 2*(4), 195-201.
https://doi.org/10.1187/cbe.03-10-0044

Tay, A. J., & Saleh, S. (2019). Science teachers' instructional practices in Malaysian and German secondary schools. *Journal of Education and Learning, 8*(4), 124-135.
https://doi.org/10.5539/jel.v8n4p124

Tytler, R., & Osborne, J. (2012). Student attitudes and aspirations towards science. In *Second international handbook of science education* (pp. 597-625). Springer.
https://doi.org/10.1007/978-1-4020-9041-7_41

Ufnar, J. A., & Shepherd, V. L. (2019). The Scientist in the Classroom Partnership program: An innovative teacher professional development model. *Professional Development in Education, 45*(4), 642-658. https://doi.org/10.1080/19415257.2018.1474487

VanMeter-Adams, A., et al. (2014). Students who demonstrate strong talent and interest in STEM are initially attracted to STEM through extracurricular experiences. *CBE—Life Sciences Education, 13*(4), 687-697. https://doi.org/10.1187/cbe.13-11-0213

Vansdadiya, R. P., Gondaliya, P. R., & Vasoya, N. H. (2023). Unleashing the power of STEM education: A comprehensive overview of its significance in today's world. *International Journal of Early Childhood Special Education (INT-JECSE), 15*(4), 325–331. https://doi.org/10.48047/INTJECSE/V15I4.35

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), 2. https://doi.org/10.7771/2157-9288.1024

Wormstead, S. J., Becker, M. L., & Congalton, R. G. (2002). Tools for successful student–teacher–scientist partnerships. *Journal of Science Education and Technology, 11*(3), 277-287. https://doi.org/10.1023/A:1016076603759

Yahya, M. S., Ismail, M. H., Salleh, M. F. M., & Abdullah, H. (2015). Science teachers' continuous professional development: Nature of in-service training and its implementation. *International Journal of Humanities, Arts and Social Sciences, 1*(1), 6-12.

Yamin, Y., Suharti, S., & Mustadi, A. (2017). Application of model project based learning on integrated science in water pollution. *IOP Conference Series: Materials Science and Engineering, 895*(1), 012153. https://doi.org/10.1088/1742-6596/895/1/012153