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A Needs Analysis Study for the Preparation of Integrated STEM Instructional Practices through Scientist-Teacher-Student Partnership (STSP)

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The current COVID-19 global pandemic forces teachers to adapt to the current situation and to come out with alternative teaching methods and STEM instructional practices to make sure the objective of equipping students with STEM knowledge, skills and capabilities could be achieved. Moreover, the declining trends of students choosing STEM subjects and careers in Malaysia have triggered research and initiatives on exploring effective approaches in science classrooms. This qualitative study intends to explore the best way to integrate STEM components through interdisciplinary and integrated approaches across science subjects (biology, physics, and chemistry) through a scientist-teacher-student partnership (STSP) initiative. The researchers employed purposive sampling to select 6 scientists and 6 science teachers for this need analysis study. Three round table discussions were conducted where data were collected through focus group interviews. Constant comparative methods were used for data analysis to identify 'needs' to be included in the integrated STEM instructional practices. The scientists and teachers validated the data obtained during a one-day workshop. Based on their consensual agreement, three (3) themes have emerged which are (1) the focus of the integrated STEM instructional practices, (2) the important elements of the integrated STEM instructional practices, and (3) the strategies for lesson implementation. The results of this study uncovered the bilateral perspectives of integrated and interdisciplinary STEM instructional practices between the scientists as knowledge practitioners and experts in STEM and teachers, the curriculum implementer and agent of change in the STEM classroom.

Keywords: Integrated STEM; instructional practices; scientist-teacher-student partnership (STSP); science teacher; teaching and learning

I. INTRODUCTION

The necessity of equipping children with STEM capabilities and their awareness of global environmental and health issues, such as the current COVID-19 global pandemic, are critical teacher endeavours. On the other hand, the demand to expose and develop children with knowledge and skills related to science, technology, engineering and mathematics (STEM) is also important even though this demand has put teachers' efforts under strain, necessitating the need to adapt and be agile in uncertain times due to the abrupt closure of schools. Many countries put STEM has been a crucial nation's agenda because qualified STEM workers equipped with STEM skills are required to maintain economic competitiveness in the global market and demands (Boe *et al.,* 2011). Therefore, continuing to teach in the same way in which they have always taught during pre-pandemic has not been an option for secondary STEM teachers anymore (Tytler *et al.,* 2019). STEM teachers need to find alternative teaching methods and instructional practices to make sure the objective to equip children with STEM knowledge, skills and capabilities could be achieved. Roschelle *et al.* (2011) mentioned that advanced economies require many innovations to grow in a country, and thus demand a steady

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supply of scientists and engineers to drive innovation is necessary. STEM education serves as a pipeline for STEM graduates seeking careers in high-demand fields. Without a consistent supply of STEM graduates, policymakers and academics have argued, the country's economic competitiveness will deteriorate (Augustine *et al.,* 2010). Therefore, all individuals regardless of background should possess STEM skills and literacy for future survival and competitions (National Society of Professional Engineers, 2013). Understanding the nature of STEM as well as familiarisation of STEM disciplines' core ideas should become a priority for all students at the school level (Bybee, 2010; National Academy of Engineering and National Research Council, 2014).

II. REVIEW OF RELATED LITERATURE

A. Issues in STEM Education

In the Malaysian context, the Ministry of Education (2018) has reported the enrolment of form four students into the science stream classes has decreased by approximately 9,000 students from 2017 to 2018; which is approximately ten times lower than enrolment into the art stream. The circumstances keep alarming as studies reported that many students chose to pursue careers in non-STEM fields even after completing secondary and post-secondary science stream courses (Zhou *et. al.,* 2019; Chin, 2019). This continuous trend is not only a hurdle for achieving the 60:40 government policy (science: art) of the annual national enrolment cohort, but in the long run, will cause a shortage of human capital in STEM-related fields, impeding the country's socio-economic development (Academy of Science, 2017). The scenarios were alarming and prompted concern among policymakers about the countries' ability to produce more STEM workers and scientific literacy for the nation's development (Van Griethuijsen *et al.,* 2015).

What are the factors that contributed to the current problem in STEM education? As reported in past studies, most students have no interest in pursuing STEM-related subjects due to how science subjects are taught (Alan *et. al.,* 2019; Christensen *et al.,* 2014). Many science lessons do not take science experiments into account, and science teachers are not competent enough to teach science (Ismail *et al.,* 2019), especially using inquiry-based learning and scientific investigation (Alan *et. al.,* 2019; Fadzil & Saat, 2013). Most science teachers taught science subjects like using a "cookbook" approach (Abrahams *et. al.,* 2013; Schwichow *et al.,* 2016). In other words, the pedagogical approach does not demonstrate how science works, and teachers who lack experience conducting scientific research would revert to teaching science almost entirely by rote (Alan *et. al.,* 2019; Fadzil & Saat, 2013; Rudolph, 2019).

Similarly, Childs *et al.* (2015) stated that the fundamental component of science in a real-world context and daily human living is not reflected in school science teaching. Students frequently perceive science as a difficult subject to learn because they are afraid of making mistakes and failing, or they lack the willingness to put forth the effort necessary to equip themselves with knowledge and skills to pursue STEM-related jobs (Fadzil *et al.,* 2019). This occurred as a result of the school's belief and perception that science learning should focus on delivering basic science concepts to prepare students to understand science concepts and perform for examinations rather than learning the knowledge meaningfully (De Jong & Talanquer, 2015; Chin, 2019). This is why STEM education remains unpopular among many students and make them perceive the subjects as irrelevant to their daily lives (Chin, 2019; Hofstein *et al.,* 2011).

To address these issues, approaches in teaching and learning during STEM lessons need to be relooked for boosting students' motivation, attitudes and interest. Moreover, the knowledge application aspects like real-life or real-world issues and problems need to be emphasised during teaching and learning. Thus, it is necessary to develop effective integrated STEM instructional practices that emphasise how science works than on the content of scientific disciplines.

B. Integrated STEM Curriculum

Implementing an integrated STEM curriculum has been determined as one of the effective instructional strategies for interdisciplinary STEM curriculum because it provides learners with a more relevant and less fragmented learning experience that stimulates their thinking skills (Furner & Kumar, 2007; Kelly & Knowles, 2016). Real-world problems are not compartmentalised into separate disciplines. However, students learn to solve problems in silo according to the subjects. To improve the weakness of this practice, cross-disciplinary problem-solving abilities need to be exposed to and acquired by students (Warr & West, 2020). Numerous studies have shown that students who have experienced the integrated curriculum approach outperform their peers who have experienced traditional classroom settings that use teaching and learning approaches that focus on separate disciplines (Hinde, 2005; Margot & Kettler, 2019). Furthermore, an integrated curriculum approach has been shown to increase students' motivation and interest in STEM-related subjects significantly. (Mustafa *et. al.,* 2016; Riskowski *et. al.,* 2009; Wang *et al.,* 2011), which results in to increase in the number of STEM graduates (National Academy of Engineering & National Research Council, 2014).

C. Challenges to Implement Integrated STEM

Many science teachers expressed a lack of confidence in explaining STEM applications to their students in the classroom (El-Deghaidy & Mansour, 2015). Mostly due to the inadequacy of STEM content knowledge (Mathers *et. al.,* 2011; Smith *et al.,* 2015). Even though there are professional development courses assisting teachers in overcoming these obstacles, teachers still find the course insufficient (Ismail *et. al.,* 2017; Nadelson *et. al.,* 2012; Zaleha Abdullah *et al.,* 2015). Additionally, teachers' beliefs, attitudes, and perspectives on teaching and learning (Ismail *et al.,* 2015) and their reluctance to change their beliefs and practices may also be another additional challenge to implement integrated STEM education (Ashgar *et al.,* 2012).

Another significant problem that the teachers faced in implementing integrated STEM lessons is absenteeism from specific guidelines on how the integrated STEM approach should be conducted (Barrett *et. al.,* 2014; Gentile *et al.,* 2012). As the integrated STEM approach emphasises the interdisciplinary aspect, teachers' role is not just teaching and explaining during the lesson, but they should play the role of facilitator. Teachers need to scaffold students to complete the task (Sias *et al.,* 2017) and guide them to draw their strength and background knowledge in their inquiry discovery mission (Neill *et al.,* 2012). However, most STEM teachers still felt unprepared to play their roles effectively for the task (Smith *et al.,* 2015).

D. Partnership with the STEM Experts

Ufnar and Shepherd (2019) propagated that one of the reasons why science teachers still face problems integrating STEM in science lessons is the lack of exposure and collaboration with experts like scientists and STEM practitioners. Teachers need help from experts who experience authentic STEM problems in their work field, thus learning from experts' first-hand experience could broaden STEM teachers' perspectives and ideas during teaching and learning. Therefore, students will benefit from a meaningful learning experience and motivate them as they can see the relevance of STEM knowledge in the real world (Schielke *et al.,* 2014). Moreover, this partnership was proven to benefit not only the students but also contributed to teachers' professional development through the process of upskilling and updating relevant knowledge for STEM integration (Houseal *et. al.,* 2014; Schielke *et. al.,* 2014; Tanner *et. al.,* 2003; Ufnar & Shepherd, 2019). The presence of scientists also provides teachers with a fresh perspective that they can pass on to their students (Schielke *et al.,* 2014). In addition, past studies asserted that collaboration between science teachers and higher education or qualified scientists had become a common approach to the reform of science education (Houseal *et. al.,* 2014; Wormstead *et al.,* 2002), and this collaboration among the scientific community and science educators have become increasingly popular in the current era (Adams & Hemingway, 2014; Houseal *et. al.,* 2014; Shein & Tsai, 2015). Specifically for this study, 'Scientist-Teacher-Student Partnership' (STSP) refers to a collaboration between three parties: university scientists, secondary science teachers, and secondary science students in preparing integrated STEM instructional practices for the benefit of STEM learning.

E. Conceptual Framework for Integrated STEM Approach

Having situated learning is a crucial element for students to achieve outcomes of the STEM lessons. Lave and Wenger (1991), explain the outcome of individuals who learn in the situated learning situation when they have the opportunity to participate in a community of practice and learn quickly as they have more opportunities to practice within the context of learning. Therefore, for this study that focuses on the STSP initiative, a specific conceptual framework for the integrated STEM approach proposed by Kelley and Knowles (2016) has been selected to be used as guidance (see Figure 1). As illustrated by the framework, integrating STEM during the lessons, also involve the guidance process of making connections to real-world applications by the experts and not just only focusing on four disciplines of STEM. The framework contains components of situated learning, engineering design process, scientific inquiry, technological literacy, and mathematical thinking and is bounded by a community of practices rope that functions as an integrated system. Based on the frameworks, it demonstrates the critical role of the 'communities of practice' or STEM practitioners/experts in moving the entire system forward for achieving the desired objectives.

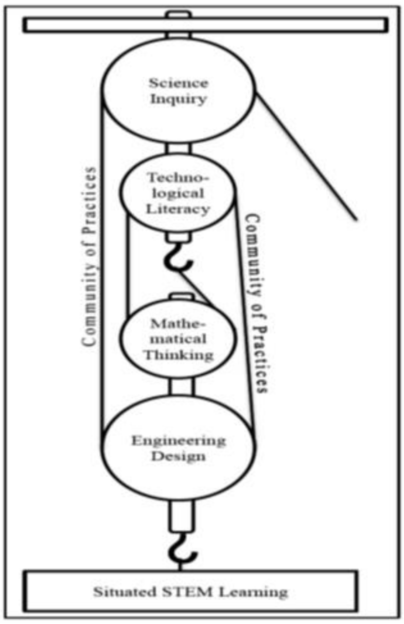

Figure 1. A conceptual framework for the integrated STEM approach proposed by Kelley and Knowles (2016)

As this study is a part of a larger study that focuses on the analysis of needs from scientists and science teachers before the preparation of integrated STEM instructional practices through the STSP initiative, therefore, the researchers explore the best way to come out with instructional practices that integrate the components of STEM through an interdisciplinary and integrated approach across science subjects namely biology, physics, and chemistry from their perspectives. This study focused on answering the following research question: What elements in instructional practices integrate STEM components through an interdisciplinary and integrated approach across science subjects, namely biology, physics, and chemistry, from the scientists' and science teachers' perspectives?

III. METHODOLOGY

To explore scientists' and science teachers' perspectives in preparing integrated STEM instructional practices, the researchers adopted a basic interpretive study under qualitative research design. This approach is appropriate in acquiring rich data and information to answer the research question. As Merriam (2009) mentioned, qualitative research aims to comprehend the meaning that people have constructed, how they make sense of their world, and the experiences they have in the world. Furthermore, it allows participants to 'place importance on context and process based on their experiences' (Lattrell, 2010). Thus, it is believed that exploring participants' responses regarding their perspectives on preparing integrated STEM instructional practises for students' meaningful learning is the most appropriate technique. Scientists' experience with scientific ideas, knowledge, and skills and science teachers' experience with educational aspects could be gathered, and these phenomena under study could only be explored using qualitative inquiry (Merriam, 2009).

The researchers employed purposive sampling (Creswell, 2009) to choose scientists and teachers to be involved in the data collection process. Six (6) scientists and six (6) science teachers are willing to participate in this study. The scientists are from industries and also universities that have an educational background in pure and applied science. In contrast, science teachers have experience in teaching Physics, Chemistry, and Biology in secondary school. The researchers also set criteria for selecting participants based on their work experience, with both scientists and science teachers required to have at least five years of experience and to be working in their respective fields. This is important to ensure that they have enough experience in their field and would be "knowledgeable informants" (Lincoln & Guba, 1985).

For this study, the primary source of data is verbal data, gathered through focus group interviews. The interview structure allows researchers to respond to participants' responses throughout the session, such as by probing for clarification to better understand the participants' emerging responses (Merriam, 2009). The interview adhered to a set of peer-reviewed and validated interview protocols. As stated, three series of round table discussions were conducted for this specific need analysis study, in which data were collected via focus group interviews. In the fourth week, the data collected through three round table discussions were presented and validated by scientists and teachers during a one-day workshop. The data collection process took four weeks in total. Audio recorders were used to capture the entirety of the interview. The researchers analysed the data using the constant comparative method (Merriam, 2009). All audio recordings were transcribed verbatim. After becoming familiar with the transcriptions' data, the data were read several times and then chunked and coded. The emergence of codes resulted in the emergence of categories and themes. Data collection and analysis processes were conducted iteratively until saturation was achieved (Patton, 2015) because information received from the participants started to become redundant (Merriam, 2009).

For ethical concerns in this study, all participants were given an informed consent form. Denzin and Lincoln (2011) highlighted this serves as the backbone of ethical research. The phrase is comprised of two important components, which requires careful consideration which is 'informed' and 'consent'. Participants must be informed about the roles and tasks that they need to do, how their data will be used and reported, and also the potential consequences (if any). Thus, the participants have to sign the consent form to participate in this study, including knowing and understanding their rights to access the information and withdraw from the study at any time.

IV. RESULTS AND DISCUSSION

Based on the analysis, the researchers found that the scientists and science teachers have numerous ideas for developing integrated STEM instructional practices through the scientist-teacher-students partnership (STSP) initiative. Even though there are different ideas between the participants, the researchers found that the goal is to focus on practice that could give students a meaningful learning experience. Based on their consensual agreement, three (3) themes have arisen as the 'needs' in preparing the integrated STEM instructional practice, which is (A) the focus of the integrated STEM instructional practices, (B) the important elements of the integrated STEM instructional practices, and (C) the strategies for lesson implementation. The following sub-sections describe the themes more extensively:

A. The Focus of the Integrated STEM Instructional Practices

The focus of the integrated STEM instructional practices reflects the important aspects highlighted by the scientists and science teachers that should be prioritised in preparing the integrated STEM instructional practices. Based on the participants' responses, three main categories have been classified under this theme namely: (1) the connecting concepts, (2) STEM skills enhancement and, (3) applications of STEM knowledge. The subsequent sub-headings will describe the three categories more extensively:

1. The connecting concepts

This is one of the aspects that most of the participants highlighted. The participants believed that real-world problems exist as interdisciplinary rather than fragmented as a single discipline. Hence, the current practice in STEM class did not reflect the actual circumstance of the real-life problems. The participants concurred that students need to be exposed to connecting concepts within and/or inter STEM disciplines during science lessons to overcome this issue. The purpose is to help students to be familiar with the real situation and prepare them well to face real-world problems. The following excerpts showed the participants' concerns.

> *...to explain concepts or knowledge of physics, chemistry and biology that involved during conducting STEM activities. Students should aware. For example, like what I have experienced with the students on car racing activity (STEM project during Science week), we discuss how the shape of the car affects the movement and speed of the car that they have produced. The chemistry aspects that helped to move the car through the reaction between calcium carbonate and vinegar that students put inside the balloon also being discussed and explained. So, students* ***can see clearly and can relate the concepts they learned with the application aspect*** *and this is very important.*
>
> *(Teacher A)*

> *... as real-world problems out there not appear as single discipline. It requires students to understand the whole aspects as it is interrelated disciplines. Students* ***should have ability to connect the knowledge or concepts from one discipline to another disciplines****. We should consider having this kind of*

integrated STEM activities that ***focusing on these connecting concepts and interdisciplinary aspects.***

(Teacher C)

..., after that, the students discuss the challenges that they faced and ***they have to relate the concepts in all disciplines of STEM*** *based on what they have experienced. It is effective. Because students enjoyed the activity, on the same time they* ***learned and understand the interdisciplinary knowledge and concepts*** *of what they have discussed.*

(Teacher D)

The exposure of interdisciplinary should be given priority. Like we are experiencing now, we have to deal with real problems that have all disciplines. So, students should know this at the school level and be familiar with all these connecting concepts. Then they are ready to face the real world of occupation.

(Scientist B)

Syllabus in school focus on separate discipline while real-world issues and problems do not appear as single discipline. So to me, it is really important to design the integrated STEM lesson that provide students with real-world problems. They will better understand the real world and ***know the importance of dealing with interdisciplinary activities and the connecting concepts*** *of every discipline.*

(Scientist C)

According to Kelly and Knowles (2016), connecting concepts and contents in science classrooms through integrated STEM activities could make science more relevant in real-world situations. Connecting concepts encourages scientific inquiry and curiosity and openness to new ideas and influences students' interest in science (Holstermann *et al.,* 2010). It also contributes to the meaning of science education (Wang *et al.,* 2011). Connecting ideas across disciplines is more difficult when students have little or no understanding of the relevant concepts in their respective disciplines. Furthermore, students are unfamiliar with or do not naturally integrate their disciplinary knowledge. This is why teachers must play an important role in assisting students in eliciting relevant scientific or mathematical ideas in an engineering or technological design context, connecting those ideas productively, and reorganising their ideas in ways that reflect normative, scientific ideas and practises (National Academy of Engineering and National Research Council, 2014).

2. STEM skills enhancement

This is the second category under the theme 'the focus of the integrated STEM instructional practices. Most of the participants mentioned that STEM skills should be enhanced by implementing integrated STEM instructional practices. Thus, preparing the instructional practices should consider having STEM activities or projects that embed STEM skills. The participants mentioned that lacking STEM skills would hinder students' ability to face real-world challenges, especially solving problems.

...we should design activities that ***involve many STEM skills****. For example, like what I have mentioned just now, on parachute activity, we should analyse their STEM skills based on what they have proposed on* ***the design of the parachute, the engineering design process on the developing aspect, the critical thinking aspect*** *and also their ideas on how to make sure longer time taken for the parachute to reach the ground. All these* ***enhance their drawing skill, design skills and also engineering design skill.***

(Teacher D)

... that's why when we pre-determine the STEM skills involve, then easier for us to come out with the tasks to be given to the students. As integrated STEM covers interdisciplinary aspects, ***so many STEM skills could be embedded into the instructional practices so that they can acquire both knowledge and skills especially on the hands-on aspect****. But we should properly plan la..*

(Teacher E)

...STEM skills like problem-solving, higher-order thinking, analytical thinking, and working independently. Because nowadays, ***young generation cannot critically solve problem and they bring spoon-feeding culture that they have experience in school*** *into their job world. To me, it's* ***good to help them to acquire these STEM skills at school level****.*

(Scientist A)

*...****skills that help the students to become more critical person, and also to help them to survive for the future****. I think many* ***STEM skills could be considered to be embedded into STEM activities*** *that we will design later. Besides, the skills involved in the design of STEM activities should also be measured and reported.*

(Scientist E)

...proper planning to cover what STEM skills should be embedded in the instructional practices. I think it is really important ***to make students familiar and experience with STEM projects or activities that at the same time enhance their STEM skills.*** *Show them that knowledge alone is insufficient, they also need to have skills to solve problems....*

(Scientist F)

According to Bryan *et al.* (2015), critical thinking, problem-solving, communication, and collaboration are 21st-century STEM skills. All individuals are expected to possess these STEM skills to function effectively as citizens, employees, and leaders. Researchers have looked at other facets of STEM skills to broaden the scope, such as technological and engineering design capabilities. Past studies reported, by actively engaging students in technological usage and engineering design process, they are not only learning the application of the knowledge but also deepening their understanding of core ideas in all STEM disciplines (Guzey *et. al.,* 2016; Hernandez *et. al.,* 2013; Shahali *et al.,* 2016). Additionally, Riskowski *et al.* (2009) concurred that by practising engineering design activities, students would be able to improve their knowledge of science, technology, and mathematics, as they fill the gap between factual content knowledge, abstract knowledge, and application.

3. Applications of the STEM knowledge

This third category under the theme 'focus of the integrated STEM instructional practices' has emerged on the aspect related to applications of STEM knowledge. The majority of the participants highlighted this is the most critical aspect that the students lack nowadays. Besides, when students fail to apply the STEM knowledge into the real-life application, they cannot see the relevance of learning the knowledge and eventually affect their motivation and interest in STEM learning and their career pathway in STEM-related fields. Thus, the aspect of STEM knowledge applications should also be embedded into the integrated STEM instructional practices that will be prepared through STSP.

> *...not just on connecting aspects,* ***the application of STEM knowledge and concepts*** *also important and must be seen in the instructional practices.*
>
> *(Teacher A)*

> *...****don't forget about the application of knowledge as well in the activities****. Integrated approach really focuses on this. When students apply the knowledge to complete the tasks given, students also indirectly acquire STEM skills.*
>
> *(Teacher B)*

> *...****application aspect that they failed to have*** *nowadays. When having STEM activities and projects,* ***they have to apply the STEM knowledge****. We provide specific learning experiences through the instructional practices that we designed. So we provide a good platform for them to experience this.*
>
> *(Teacher F)*

> *...it is important as 'application' cover on HOTS aspect. To me, this is the real situation that we want students to experience. They* ***must have and know how to apply and use the knowledge*** *for their survival especially in the STEM fields.*
>
> *(Scientist B)*

> *...application of STEM knowledge that they have learned into the projects or tasks that we design in the instructional practices.* ***We should look at this application aspect seriously****, so students will get benefit from this.*
>
> *(Scientist C)*

> *...to apply STEM knowledge, they should understand knowledge and concepts first. So they will* ***experience many things like the application of STEM, connecting STEM knowledge,*** *acquire STEM skills and also many STEM activities and projects in these instructional practices. Good for the kids.*
>
> *(Scientist D)*

Sanders (2009) and Pearson (2017) coincided that integrating STEM in class requires a clear connection between STEM disciplines and their application to real-world problems. Though the integrated STEM approach has been widely implemented in many countries, embedding the applications of STEM knowledge in teaching is still not widely implemented (Kelly & Knowles, 2016). As English (2016) highlighted, integrated STEM does not simply teach each STEM discipline concurrently; rather, it focuses on the core content of each discipline (Urban & Falvo, 2016) and interdisciplinary processes. This would give an advantage to STEM instructors to highlight the vast applications of STEM knowledge and show their relevance to real-world problems to students. Thus, students can apply the interdisciplinary element they have experienced, and science lessons would be more meaningful (Lou *et al.,* 2017).

B. The Important Elements of The Integrated STEM Instructional Practices

The second theme that emerged is the important elements of the integrated STEM instructional practices based on recurring patterns of participants' responses. According to the participants, these elements should be embedded into the instructional practices to elevate students' experience in learning integrated STEM lessons besides, giving them a meaningful learning experience. Three categories which are (1) authentic context, (2) active interaction, and (3) collaborative experience, were included under this theme. The details of the categories will be discussed in the following sub-headings:

1. Authentic context

Creating authentic learning experiences is the most difficult aspect of teaching and learning. However, providing students with an authentic learning experience by applying scientific knowledge to real-world situations is essential for deep understanding. Based on the interviews, the majority of the participants highlighted the importance of designing an authentic learning context in the integrated STEM instructional practices in science lessons.

> *...as learning should be* ***authentic, real and hands-on for them****, the environment of learning will be different.*
>
> *(Teacher A)*

> *...like the real-world problems.* ***We should bring these authentic problems and situations into the class.*** *Provide problems and let them to explore and discuss. Scientists here can share the real problems out there with us.*
>
> *(Teacher B)*

> *...again, it is authentic,* ***like the parachute activity that I mentioned just now. Students directly experience and understand the concept instead of only knowing the theories.***
>
> *(Teacher D)*

> *...in the lesson planning, of course, at the beginning we must determine what we are going to do with the students. Rather than showing them videos or notes,* ***we provide them with authentic activities.***
>
> *(Teacher F)*

> *.... they should know* ***what's actually happen in the scientific world.*** *That's why we discussed just now to bring the authentic situation and challenges into the instructional practices and we design activities based on the authentic situation.*
>
> *(Scientist A)*

> *...and of course, the learning environment should be there. Students must have* ***real authentic hands-on activity****....*
>
> *(Scientist B)*

> *.... because I'm not a teacher, however the type of activities and also the teaching approach* ***should consider having this real-world situation or authentic situation*** *because students learn through this authentic learning.*
>
> *(Scientist C)*

The researcher even asked further why authentic learning is important, and these are some of the excerpts to show their justifications on the benefits of using authentic context to students:

> *The authentic learning context really helps students to achieve the outcomes of the lesson.* ***Like car racing activity that I have explained, they will directly feel and experience the whole learning process.*** *They even can* ***develop some important skills through the real activity that they have done.***
>
> *(Teacher A)*

> *...as we bring the real situation and problems into the lesson. These authentic issues and situations will* ***help students to understand theories and also on the practical aspect and develop their STEM skills.*** *Indirectly* ***help them to be prepared before entering the real job world.***
>
> *(Scientist C)*

Creating an authentic learning environment in the science classroom while integrating STEM is not an easy task for many STEM teachers. Ciolan and Ciolan (2014) posited that teachers face a significant challenge in embedding authentic context in teaching. Not only that but also, the concept of authenticity is widely debatable in STEM teaching (Anker-Hansen & Andreé, 2019). Herrington and Parker (2013) define authenticity as the presence of an authentic context, authentic task, expert performances, multiple perspectives, collaboration, reflection, articulation, metacognitive support, and also authentic assessment. On the other hand, earlier studies on authentic learning in STEM education focused on limited aspects like the critical nature of establishing an authentic context for conducting an authentic assessment (Bulte *et. al.,* 2006; Fox-Turnbull, 2006; Svärd *et al.,* 2017). Therefore, according to Luttfi (2020), to have authentic learning in integrated STEM lessons most importantly is to provide students with the opportunity to learn through real learning experiences like in a work-based or contextual environment (Kennedy & Odell, 2014) where it provides an avenue with the ability to apply their knowledge, learn through experience and to recognise their potential to grow significantly beyond what they have acquired or school practice (Luttfi, 2020).

2. Active interaction

Active interaction reflects engagements that need to be presented in instructional practices for the active learning experience. For this category, most participants mentioned the importance of having two-way interaction between students-teacher and among students themselves during science lessons. As the integrated STEM approach involve an interdisciplinary aspect that usually focuses on meaningful learning, thus active interaction between teacher and students is a must. Interaction is deemed an important platform for knowledge transfer and as a means to facilitate and assess the learning process. The following excerpts depict the idea:

> *...it is not just about providing platform for the students to explore real-world problems, but the* ***teacher also should always ask the students and actively discuss on the problems*** *to make sure they realise and know what they are doing.*
>
> *(Teacher A)*

> *...the engagement with students also important.* ***We might think students understand until we ask question, then we will know they are still with us or not****.*
>
> *(Teacher C)*

> *...always engage and help the students to solve the tasks. Helping here means* ***try to scaffold the students, not giving the solutions. Students need our attention and when we actively interact with them,*** *they realise how that we concern about what they are doing.*
>
> *(Teacher E)*

> *...I think there must be* ***two ways interactions****. Not just giving kids with the tasks and ask them to complete the tasks.* ***We need to monitor the progress and even ask them from time to time what they are doing and the reasons why they choose to have those solutions.***
>
> *(Scientist D)*

> *...and to me,* ***we should keep asking why and why for them to think more and to trigger their critical thinking*** *aspect. Thus, it helps to polish some of their STEM skills.*
>
> *(Scientist E)*

> *... as I have mentioned****, how to measure they acquire STEM skills if the teacher does not actively engage with their kids?*** *How to know they have acquired those skills?*
>
> *(Scientist E)*

Efficacious teaching relies on active student engagement, which has been shown to have numerous benefits for students. It has been proven in numerous studies that active participation in teaching and learning increases student motivation to learn and academic achievement (Ambrose *et. al.,* 2010; Brown *et. al.,* 2014; Freeman *et. al.,* 2014; Hodges, 2015; Nilson, 2016; Theobald *et al.,* 2020). As shown in a meta-analysis of 225 studies in STEM courses conducted by Freeman *et al.* (2014), the failure rate for one-way teaching was 1.5 times higher than for lessons in which students were actively engaged. Additionally, Theobald *et al.* (2020) noticed that active engagement reduced achievement gaps between underrepresented minority students and their peers by 33 per cent and passing rate gaps by 45 per cent. Therefore, instructional practices that focus on integrated STEM elements must be designed carefully for students' meaningful learning because there are many studies reported not only on students' significant improvement in their academic achievement but also lead to successful completion of science courses and desire to pursue STEM degrees (VanMeter-Adams *et al.,* 2014).

3. Collaborative experience

This category explains the aspect of collaborative work to be included in the instructional practices. The participants believe that this element could promote teamwork and collaboration skills among the students. Based on the participants' responses, all participants agreed that this element is important and must be included in the integrated STEM instructional practices that will be developed. The following excerpts were the responses given based on the researcher's question.

> *Researcher: So, do you think the collaborative aspect is important? Could you please justify?*

> *Definitely yes, and this is the* ***key to the success*** *of STEM lessons.*
>
> *(Teacher A)*

> *Of course. Because like we discussed just now,* ***there must be group work*** *activities.* ***Through group work, students will experience many things and even they learn with their friends.***
>
> *(Teacher B)*

> *Yes. This is one of the important skills that students should have.* ***I prefer to see how they manage to work in a team****. Even we can see the product of group work better compared to individual work.*
>
> *(Teacher D)*

> *To me it is important. Not just during school time,* ***when they work in the future as well, this collaborative work is a must for everyone.***
>
> *(Scientist A)*

> *As we provide them with real-world problems and also emphasise on application of STEM knowledge****, to me they cannot run from having collaborative work. They should solve the tasks in the team.*** *This is really good for them,* ***they learn from each other.***
>
> *(Scientist E)*

> *Yes, of course.* ***This actually requires skill and not every student could work in a group and even could contribute through group work.*** *So, we should expose them to have this skill and even guide them on how to work in the group.*
>
> *(Scientist F)*

Guzey *et al.* (2016) discussed the importance of providing exposure and opportunities for students to participate in teamwork, which has been shown to improve their teamwork skills. Besides, other researchers emphasised the importance of collaborative work for stimulating teamwork abilities and nurturing communication abilities through interactions between the group members (Bryan *et. al.,* 2015; Roehrig *et. al.,* 2012; Stohlmann *et al.,* 2011). The findings obtained are actually in line with the studies that have been reported. Additionally, collaborative work also creates a positive interdependence among group members, which is deemed imperative in creating a positive learning environment in class, especially during science lessons that integrate STEM disciplines (Ashgar *et al.,* 2012). Therefore, these instructional practices should be properly designed to encourage students to be active (Stohlmann *et al.,* 2011) through a collaborative learning environment for meaningful STEM learning (Kennedy & Odell, 2014).

C. The Strategies for Lesson Implementation

This is the third theme that has emerged through the data analysis process. This theme covers the strategies deemed as effective by participants to implement integrated STEM instructional practices in science lessons. Based on the participants' responses, three strategies emerged as categories which are (1) students-centred approach, (2) inquiry-based activities and (3) hands-on learning. The subsequent sub-headings will describe the main categories more comprehensively:

1. *Students-centred approach*

This is one of the pedagogical approaches that focus on knowledge acquisition through students' engagement in class instead of the teacher-centred approach. All participants agreed that this approach reflects the actual characteristics of integrated STEM learning. As the integrated STEM approach focuses on an interdisciplinary STEM element that emphasises STEM knowledge and skills, the empowerment of the learning in terms of students' discovery process should be practised with the teacher's assistance as the facilitator. This strategy must be included in the integrated STEM instructional practices that will be developed through STSP. The following excerpts showed the participants' responses:

> *...and* ***using student-centred is the most suitable approach****. However, we should monitor the students because some of the students easily get distracted and not focus on the tasks given.*
>
> *(Teacher A)*

> *...try to* ***focus on students driven activities****. We* ***let them to come out and propose the best solutions based on the problem given****. Then we can assess how critical and creative they are.*
>
> *(Teacher C)*

> *...even though we agree to have students-centred approach for STEM activities, doesn't mean we leave everything to the students. We should guide and help them as well because sometimes, they totally lost. We also should play our role for the outcome of the lesson to be achieved.*
>
> *(Teacher F)*

> *...students centred means it should* ***start from the students. We let them to think, to discuss and also to come out with their own planning, ideas, try and error process and so on.*** *When they failed, then they learn something new, and it is a cycle process before they can solve the tasks. This is where we should put ourselves as facilitators to facilitate the learning process that occurred.*
>
> *(Scientist B)*

> *...as STEM involve many disciplines, many concepts and also skills, thus, activities, lesson and even learning environment must be planned properly. This is where* ***we provide a platform for students to discover on their own on the interdisciplinary aspects and relate with real-life application. They will become more critical person and it is good exposure for them.***
>
> *(Scientist C)*

Numerous studies have demonstrated that using the student-centred approach has increased students' higher order thinking and increased students' motivation in STEM-related subjects (Boddy *et. al.,* 2003; Moustafa *et al.,* 2013). Guzey *et al.* (2016) also noted that lessons and activities should be student-centred in a science classroom since it helps students build better comprehension and abilities. Additionally, it has been established that when students solve issues or complete tasks using a student-centred method or student-driven activities, students' motivation, critical thinking, and academic skills greatly improve in STEM classrooms (Tamim & Grant, 2013). Moreover, Laopaisalpong (2011) and Plangwatthana (2013) also reported that student-driven activities through integrated STEM lessons provide students with the experience of engineering design and technological knowledge, becoming STEM literate and capable of dealing with complex problems. Thus, this approach is beneficial since it transforms students to become active users of knowledge and skills in the class.

2. *Inquiry-based activities*

This is the second category that emerged under the theme 'strategies for lesson implementation. As the term 'inquiry' means asking for information, thus inquiry-based activities reflect any activities where the aspect of 'questioning' is an important part of the teaching approach. The majority of the participants suggested STEM activities that they will design in the instructional practices should be using inquiry-based learning.

> *... activities that focus on inquiry-based learning are the most effective strategies for developing students' STEM skills. Like why I did in the car racing activity,* ***I asked students about the design aspect they have produced. I even trigger them to think about the materials that they used if we replace them with other materials and also the shape of the car that they produced. The different time taken during racing car also being asked and they have to critically think and explain the reason why.*** *And I could see how they use their critical thinking skill.*
>
> *(Teacher A)*

> *...we have IBSE (inquiry-based science education) technique as suggested by the ministry for STEM learning. Like parachute activity, that I have done with my students,* ***I use inquiry approach to ask students many things especially on the design, process, materials and even on the application aspect. They have to discuss with their group members, and they actually learned many things****.*
>
> *(Teacher D)*

> *...I think, besides giving problems and tasks, we should also* ***use inquiry approach to explore their ideas and their answers based on their solutions.***
>
> *(Teacher E)*

> *...as I mentioned previously, as we facilitate the learning process,* ***we should also inquire the students on what they are doing.*** *They have to think and decide first before propose or giving the solutions to the problems given.*
>
> *(Scientist B)*

> *...****we should frequently ask question to the students.*** *The type of question should focus on the application part and higher-order thinking questions depending on the STEM activities that going to be designed.*
>
> *(Scientist C)*

> *To me,* ***inquire based learning*** *is one of the effective teaching strategies to be used in the STEM lesson. It* ***provides active participation and also they will be many discussion and arguments*** *during the teaching and learning and it's good.*
>
> *(Scientist F)*

As reported by many studies, students discover new concepts and develop new understandings through inquiry-based activities (Satchwell & Loepp, 2002; Stump *et al.,* 2016). Hence, the teacher must use the 'questioning technique' to promote knowledge construction (Wells, 2016) and assess students' existing concepts through dismantling objects, making predictions, observing, and recording the explanations (Satchwell & Loepp, 2002). Stump *et al.* (2016) also highlighted, incorporating inquiry-based activities into the science classroom could stimulate students' current knowledge. As a result, students can use their past knowledge to generate new ideas, design and execute experiments, and develop unique concepts. Ultimately, students may demonstrate an in-depth understanding of the discussed subjects (Satchwell & Loepp, 2002). However, teachers must play a role in facilitating to ensure successful implementation of inquiry-based learning. Numerous studies have proven the importance of providing adequate guidance to assist students in achieving the desired conceptual change (James *et. al.,* 2000; Satchwell & Loepp, 2002). Teachers must guide students by probing for flaws in their reasoning and/or research design, eventually assisting them in arriving at a solution (Buck *et al.,* 2008).

3. Hands-on learning

This is the third category that emerged under the theme 'strategies for lesson implementation. Most participants believed that hands-on learning is also another instructional strategy that could help students acquire STEM knowledge and skills. The hands-on activities provide an authentic learning experience and a platform for students to apply theories that they have learned into practice.

> *...the nature of STEM activity must be hands-on activity.* ***Students must involve in these hands-on activities to help them acquire STEM skills and STEM knowledge.***
>
> *(Teacher B)*

> *I think, we should* ***focus on hands-on learning****. Like we highlighted on authentic learning just now, it should be conducted through hands-on.*
>
> *(Teacher C)*

> *...to provide a meaningful learning experience, students must do STEM activities on their own.* ***They must experience these activities through hands-on, then it helps them to acquire the skills involved.***
>
> *(Teacher D)*

> *...I believe in hands-on and student-driven activities. Through these, the outcome of the lesson can be measured and achieved.* ***Students also experience STEM knowledge directly based on what they are doing through hands-on learning.***
>
> *(Scientist A)*

> *...if we discuss on STEM skills acquisition like critical thinking skills, problem-solving skills and collaborative skills, students must be exposed to a real and hands-on activity. Thus,* ***they learn through what they have***

experienced. Besides, if failure happens, they going to look back on the process and to me, this only could be done through hands-on.

(Teacher E)

The instructional practices through hands-on learning and hands-on activities help the students to be able to see real-life illustrations of the knowledge. Since STEM knowledge is frequently abstract and complex, engaging students in manipulating objects can help them to solidify their abstract knowledge and comprehension (Zeluff, 2011). Additionally, Pluck and Johnson (2011) described that hands-on activities and experiences also stimulate students' curiosity and interest in learning. Numerous studies have also demonstrated that hands-on activities focused on authentic problems foster a positive classroom environment, a significant factor in determining students' attitudes toward school science (Holstermann *et. al.,* 2010; Ruby, 2001). Ultimately, STEM learning becomes more meaningful to the students (Wang *et al.,* 2011).

V. CONCLUSIONS

In conclusion, it is believed that if integrated STEM instructional practices are designed effectively despite facing the current COVID-19 global pandemic, it can give benefit towards students on the aspect related to STEM knowledge and concepts, acquisition of students' STEM skills, application of STEM knowledge and also increase students' interest in learning STEM-related subjects in secondary school, as this partnership has proven to enrich students' learning experiences. The findings indicated the proposed elements that are important to consider during the designing and preparing of integrated STEM instructional practices through interdisciplinary and integrated approaches across science disciplines from the perspective of science teachers and scientists involved in this STSP project. The combination of existing ideas and collaboration has provided the 'needs' in developing instructional practices with positive impacts on STEM education. As contended by many scholars, involving scientists in STEM education provide a platform for students to see the reality of science in a real-world setting, thereby increasing their interest in STEM (Houseal *et. al.,* 2014; Wormstead *et al.,* 2002). However, teachers should play an eminent role to connect and bring the whole experience into their science lessons for meaningful STEM learning.

VI. REFERENCES

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