Development Of The Secondary School Quantum Physics-Stem (SSQP-Stem) Instructional Module For Physics Teachers: A Fuzzy Delphi Method (FDM) Approach

Laurah Markus and Mohd. Zaki Ishak

***Abstract* – Education transformation demands teachers to rethink the purpose of teaching for a more meaningful and sustainable education. It requires effective teaching to improve knowledge transfer efficiency and generate successful educators with teaching strategies that positively impact students' life and career, including instilling critical skill sets and introducing new concepts with real-world applications. Therefore, an instructional module with an integrated STEM education approach for physics teachers in conducting quantum physics (QP) lessons was developed through expert consensus under the Fuzzy Delphi Method (FDM). This study obtained sixteen experts' consensus using a questionnaire for data collection. The questionnaire with a seven-point linguistic scale was generated from the TABA Curriculum model components and the Physics Standards-based Curriculum and Assessment Document (*DSKP*). The results of the data analysis identified that 100 out of 103 elements of the instructional module were accepted based on the expert consensus value ≥ 75%, the threshold value (d) ≤ 0.2, and the fuzzy score (A) (α – cut) value ≥ 0.5. The experts suggested that three items from the learning outcomes component need to be replaced with more appropriate items. Overall, the components and elements of the instructional module were accepted, with several adjustments and corrections done to improve the module's content appropriateness.**

***Keywords* – Design & Development Research, Fuzzy Delphi Method, integrated STEM education, inquiry-based learning, instructional module, Quantum Physics**

I. INTRODUCTION

Transforming education is inevitable in uncertain global shifts, as the Covid-19 pandemic, which disrupted every aspect of the worldwide system in the past two years, including education, prompted dramatic adjustments that finally shifted the school system to the virtual class during the phase of mobility control order from the authorities (Daniel, 2020; Govender & Olugbara, 2021; Mohd & Shahbodin, 2021). It has caused problems for teachers in managing virtual classrooms, and the effectiveness of the instructions has been doubted (Daniel, 2020; Govender & Olugbara, 2021).

Despite the ongoing challenges, teachers are responsible for educating students in acquiring the necessary knowledge, skills, and values to generate the human capital needed to pursue a civilised nation (Academy of Sciences Malaysia, 2018). In achieving the aspiration, teachers are expected to apply the STEM education approach as it is seen as effective in generating young talents in science and technology, which is crucial in this modern era (Amelia & Lilia Halim, 2019; Muhammad Hadi Bunyamin & Finely, 2015; Pearson, 2017).

However, it was reported that many teachers still lack training and knowledge in implementing teaching and learning with the STEM education approach (Nur Farhana Ramli & Othman Talib, 2017; Suraya Bahrum et al., 2017). They are lack of guidance, content knowledge, and STEM instructional skills (Maruthai, 2019; Siew et al., 2015). The insufficiency of facilities and materials also contributed to the problem in conducting school or classroom STEM projects (Nur Farhana Ramli & Othman Talib, 2017; Siew et al., 2015). Teachers also needed detailed steps, guidance, game suggestions, material suggestions, a module with detailed lesson plans with adaptable time allocation, and HOTS component incorporation in STEM learning activities (Farihah Mohd Jamel et al., 2019). Therefore, these issues have contributed to the decrease in the number of talents and disinterest in STEM (Academy of Sciences Malaysia, 2018; Amelia & Lilia Halim, 2019).

The achievement in TIMSS and PISA with among the lowest in two-thirds of the country involved (Suraya Bahrum et al., 2017) shows that more effort is needed to address the teaching and learning issues to attract more students to pursue the STEM education streaming and change their negative perceptions of STEM subjects (Bunyamin & Finley, 2016), and explore alternatives for traditional teaching with more authentic and real-world based learning (Thibaut et al., 2018).

As this study focuses on the teaching and learning for secondary school QP, research on the needs analysis for developing an instructional module for this topic revealed that teachers lack resources to assist them with physical and online classrooms for QP lessons, especially in conducting lessons with the integration of STEM education activities.

Therefore, the secondary school QP with an integrated STEM education instructional module is developed to cater to the needs of physics teachers in conducting QP lessons with inquiry-based learning (IBL) to instil knowledge, skills and values through the designed learning activities in the module. This module is developed by obtaining experts' consensus on the suitability of the module's content through the Fuzzy Delphi Method (FDM), as discussed in the following sections.

II. PROBLEM STATEMENT

STEM education has been highlighted as the main agenda in education transformation as it is seen as important

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in driving economic and social growth (Academy of Sciences Malaysia, 2015, 2018; MOSTI, 2017). It is believed to be relevant with the rapid advancement in science, technology and innovation as it emphasises learning with real-world issues and current situations (Hu et al., 2020; Kelley & Knowles, 2016). Along with the enforcement, teachers have been the centre of attention to ensure they can progress and execute the educational development plans at the school level (Abdullah et al., 2017; Academy of Sciences Malaysia, 2017; MOE,2016c).

However, it was seen that teachers have difficulties executing STEM education (Abdullah et al., 2017; Amelia & Lilia Halim, 2019; Academy Science of Malaysia, 2018; Nur Farhana Ramli & Othman Talib, 2017; Shahali et al., 2015). Studies show that teachers have inadequate training and information from the authorities, are burdened with school workload and lack preparation for effective learning activities (Farihah Mohd Jamel et al., 2019; Nur Farhana Ramli & Othman Talib, 2017; Suraya Bahrum et al., 2017).

As the current study focuses on the QP topic for secondary school, it is anticipated that it may be challenging to integrate STEM education with QP because it is newly added to the physics curriculum, is different from classical physics and has a long unclear interpretation in history (Angelo et al., 2014). Besides, modern QP experiments are lacking for the secondary school level (Bitzenbauer & Meyn, 2020), and the textbook may be the main resource for teachers to guide students to conduct QP learning with STEM approaches that might neglect to emphasise essential skills such as designing skills and real-world problem-solving in their teaching and learning activities (Academy of Science Malaysia, 2015; Toma & Greca, 2018). It was also reported that teachers with insufficient engineering and technological skills have hindered and demotivated them from pursuing integrated STEM education and adhering to their traditional teaching routine (EL-Deghaidy et al., 2017; White, 2014).

Studies show that QP concepts are difficult for teachers and students to understand despite the syllabus only focusing on the qualitative content with the fundamental mathematical application (Bungum et al., 2015; Myhrehagen & Bungum, 2016; Johansson et al., 2018; Stadermann & Goedhart, 2020). As the quantum theory contradicts classical physics, students need to be aware of and understand the different perspectives between classical and modern views at the microscopic level of matters (Bungum et al., 2015; Ravaioli, 2019). It is challenging as it is not only new and different but also abstract, which requires intuition, mental models and qualitative reasoning to interpret and explain them (Dutt, 2011; Malgieri et al., 2017; McKagan et al., 2008). Thus, effective instructional tools are needed to facilitate students' visualisation to dissipate the difficulties in understanding the concepts (Bungum et al., 2015; Habibbulloh, 2019; Kızılcık & Yavaş, 2016; Polatdemir et al., 2004; Ravaioli, 2019).

Nevertheless, teachers must equip themselves with pedagogical strategies to manage inadequate laboratory equipment (Habibbulloh, 2019) and instruction skills to bring this topic to a constructive and meaningful learning environment. Therefore, this research aims to provide the instructional module with an integrated STEM education approach and instructional tools for QP L&F, such as Hallwachs' experiment (Ravaioli, 2019) and the PhET photoelectric effect (McKagan et al., 2008) to construct students' understanding of the topics.

III. LITERATURE REVIEW

Integrated STEM education approach in teaching and learning

Studies showed that integrating STEM education in physics is beneficial as many scholars and educators approve of the STEM education approach for successfully guiding students in problem-solving and understanding abstract concepts (Lin et al., 2019; Selisne et al., 2019; Siew et al., 2015). Besides, it has improved learning quality and interconnection with the real-world context (Wang et al., 2011; EL-Deghaidy et al., 2017; Selisne et al., 2019). STEM practice is also seen to promote HOTS (Muhammad Abd Hadi & Finley, 2016; Selisne et al., 2019) and improves communication and teamwork (Wang et al., 2011). Apart from that, it increases motivation (Abdurrahman et al., 2019), mastering both programming and Physics achievement in an integrated lesson (Lin et al., 2019), and acts as a vehicle for interdisciplinary educational design (Hsu et al., 2020).

The STEM education approach emphasises IBL and PBL as learning strategies to improve student engagement and motivation in a real-world context (Blessinger & Carfora, 2015; Parno et al., 2020; Yuliati et al., 2018). It is often connected to experimental learning with authentic science practices, real-world problems, and hands-on practices (Abdurrahman et al., 2019; Hechter & Bergman, 2016; Mulder et al., 2014; Persano Adorno & Pizzolato, 2020).

IBL is important in bridging knowledge, skills and values with real-world context, whereby Jong et al. (2014) justified that inquiry laboratory and STEM are inseparable because developing the inquiry lab phase represents an innovation in applying STEM education that was also applied in several studies (Hannon et al., 2012; Jong et al., 2014; Suwarma et al. 2019; Abdurrahman et al., 2019; Parno et al., 2019). Many educators have employed the IBL of the 5E learning model to guide learning activities whereby students can actively construct their understanding throughout the learning phases, and it is often combined with the PBL strategy to nurture the design and engineering skills (Parno et al., 2019; Suwarma et al., 2019).

Technological application is emphasised in the integrated STEM education in Physics L&F whereby many studies created instructional tools like online lab (Jong et al., 2014), STEM learning resources with iPad (Hechter & Bergman, 2016), PhET and Algodoo Simulation applications facilitated with a gamification feature website (Tembo & Lee, 2017) and the application of the online platform to optimise learning (Ardianti et al., 2020a).

Besides, teamwork and collaboration with appropriate time allocation are emphasised (Hannon et al., 2012; Hsu et al., 2020), which promote positive interdependence skills (Thibaut et al., 2018). Teachers can practice their role as facilitators and focus on a student-centred learning approach to foster active learning (Hafizah Hussin et al., 2019; Wang et al., 2015). Authentic tasks are highly valued for the assessment practice, and a scoring rubric is recommended for efficient evaluation (Ardianti et al., 2020; Yuliati et al., 2018).

The integration of STEM education in teaching and learning supports the development of the 21st Century skills as it emphasises knowledge, skills, and character traits, which are necessary for generating knowledgeable and accountable citizens, workers, and leaders in the workplace in the 21st Century (Abdurrahman et al., 2019; Blessinger & Carfora, 2015; Parno et al., 2019).

Instructional strategies and learning tools for secondary school Quantum Physics

As QP encompasses radical changes in understanding the physical world and conflicts with students' classical thinking (Karakostas & Hadzidaki, 2005), more instructional strategies have been introduced to improve students' understanding of this topic. Polatdemir et al. (2004) highlighted the need for an effective instructional strategy to avoid misleading the quantum theory and be carefully conveyed to avoid serious misconceptions and confusion among teachers and students. On top of that, the current study proved that direct instruction and textbooks alone are insufficient and have caused overconfidence bias in understanding quantum theory (Testa et al., 2020). It was also argued that traditional teaching was inefficient in developing a consistent quantum model, particularly wave-particle duality, as seen in Olsen's (2002) study.

In the previous studies, many researchers recommended that the introduction of QP in secondary schools focuses on achieving a qualitative understanding rather than applying the complex mathematical approach, which is seen as increasingly crucial in secondary school physics (Dutt, 2011; Hadzidaki et al., 2000; Hoekzema et al., 2007; Myhrehagen & Bungum, 2016; Stadermann et al., 2019; Stadermann & Goedhart, 2020; Zollman, 1999). This alternative allows QP to be introduced at the secondary school level without the complexity of mathematical formalism.

One of the qualitative approaches that have been employed is teaching through QP historical development and philosophy, which researchers claim gives not only illustration and motivation but also facilitates the conceptual and cultural construction of knowledge that work for secondary school students (Bøe et al., 2018; Nielsen & Thomsen, 1990). Besides, it provided students opportunities to understand QP interpretations better and deepen their understanding of QP principles (Cataloglu, 2002; Myhrehagen & Bungum, 2016). Also, Myhrehagen and Bungum's (2016) study on secondary school students' perception of thought experiments reviewed that lack of knowledge about the purpose and historical context limits students' understanding of the physics content and thus, by exploring from a historical perspective, students' learning in QP could be deepened.

However, in Mashhadi and Woolnough's (1999) study, teaching through the historical development of the quantum particle conception led students to a misleading, mixed classical-quantum conception. They also highlighted teaching approaches that reconcile visualised QP with classical physics. Concerning this issue, Malgieri et al. (2017) employed a research-based teaching-learning sequence based on Feynman's sum over path approach to introduce wave-particle duality. This Feynman's unified model resulted in a consistent mental model of students dealing with elementary particles' quantum behaviour.

Malgieri et al. (2017) highlighted three valuable points on Feynman's approach in this study. First, it offers students a straightforward way to build a mental model, particularly wave-particle duality. Second, it allows students to identify the substantial difference between classical and QP by calculating the probability of a multi-alternative event, making the classical limit wholly transparent and allowing the classical laws to be easily derived from the rules of valid quantum objects. Third, it requires less advanced mathematics that suits the secondary school level, using a simple formal language that allows students to focus on the theory's conceptual aspects. Several studies have employed the Feynman approach, mostly assisted with simulation software, had gained positive feedback on the aspect of students' acceptance and understanding of the wave-particle duality after interventions (See: Fanaro et al., 2012; Ogborn, 2006; Pankova & Hanc, 2019; Sutrini et al., 2019).

In tackling the abstractness complication of the quantum theory, many researchers used interactive pedagogical software. Pankova and Hanc's (2019) study noted several significant benefits of interactive simulations. It offers a visual perception of system behaviour as an important aspect affecting students' mental models in QP. They also pointed out that simulations appear as a suitable alternative in the absence of real experiments and are positively accepted as a crucial motivational element of student learning. Instead of using Java, their study chose Geogebra software, which they claimed is one of the best modelling tools for math and physics education. However, it is limited to computers and not compatible with today's digital technologies such as smartphones or tablets.

Many visual integrations have been applied, and their representations have alleviated learning difficulties by promoting better understanding and meaningful learning (Dangur et al., 2014), especially in student's conceptual understanding of QP (Bungum et al., 2015; Deslauriers & Wieman, 2011; Kohnle et al., 2012; Krijtenburg-Lewerissa et al., 2017). There are numerous multimedia-based strategies with visual representations that have been introduced for teaching QP, such as PhET (McKagan et al., 2008), the Quantum Interactive Learning Tutorials (QuILTs) (C. Singh, 2008; V. Singh, 2006), and QuVis (Kohnle et al., 2014, 2015).

The use of teaching sequences with simulated virtual experiments with the Mach-Zehnder and the double-slit experiment can also develop a better quantum understanding (Müller & Wiesner, 2002). Another valuable visual representation is the PhET simulation designed and developed by the PhET team and the Physics Education Research Group at the University of Colorado (McKagan et al., 2007, 2008), research-based interactive computer simulations, animated and game-like environment for teaching and learning exploration. This active engagement-based technique has been used in several studies to improve understanding of the photoelectric effect (see: Freericks et al., 2019; Habibbulloh, 2019; Krijtenburg-Lewerissa et al., 2017; McKagan et al., 2008, 2009; Pankova & Hanc, 2019; Ravaioli, 2019; Sokolowski, 2013; Supurwoko et al., 2017).

However, McKagan et al. (2008) urged further study and development of techniques and methods for practical teaching of QP. Students also had difficulty relating the experiment to light particle behaviour (McKagan et al., 2009). This gap is essential for researchers to note and find a better alternative to improve students' learning experience.

While such simulations and computer modelling facilitate the analysis of the microscopic world, teachers, on the other hand, need support and guidance in using those resources to ensure that they can use both the contents and the instructional method in the classroom optimally. The study conducted by Michelini et al. (2002) provided teacher training and resources to offer innovative materials and tools.

Besides, teaching products such as a teaching and learning module should be flexible for teachers to adapt to their teaching style and suit their students' needs and preferences (Bungum et al., 2015). It should expose real-life applications and visualisation, parallel to Costa and Santos's (1995) view that the beginning of every learning experience in physics education must be direct interaction with the phenomenon itself. The model representation of the quantum model can be applied in differentiating classical physics from QP. In Kalkanis et al.'s (2003) study, instead of avoiding the Bohr model of the atom, they use it as a representative semiclassical model against the atom model accepted by modern science, which is Heisenberg's uncertainty to make substantial conceptual differences between classical physics and QP. These nonmathematical approaches for teaching QP have led to an adequate understanding of the secondary school level (Dangur et al., 2014; Dori et al., 2014).

Another valuable method is the IBL approach, which is a fair practice in understanding the nature of science and a crucial component of science education (Hadzidaki et al., 2000). This method was applied by Testa et al. (2020) to study the innovative guided inquiry teaching-learning sequences that follow a conceptual understanding of QP concepts with systematic instruction. The finding was seen to improve students' self-evaluation compared to traditional teaching.

Also, student engagement and understanding can be developed through this active learning, such as peer interaction, which has improved student understanding of duality and atomic models (Shi, 2013). Therefore, the right IBL approach can work superlatively with QP in developing student epistemological perspectives on science's nature. This topic is a fascinating and contemporary science that contains scientific controversies, and IBL is capable of developing the nature of the scientific views of QP (Stadermann & Goedhart, 2020). Scholars also highlighted that it is essential for students to develop their epistemological perspective of the nature of science in QP learning (Bungum et al., 2018; Hoehn et al., 2019), which includes the scientific model's role, the tentativeness nature of science, creativity, and science subjectivity (Stadermann & Goedhart, 2020). This strategy allows them to share their thoughts' subjectivity and transform them into possible objectivity through inter-subjective interaction (Costa & Santos, 1996).

Previous studies have demonstrated different strategies to help researchers design and develop research-based educational strategies. The researcher will design and develop the QP instructional module for the secondary school level by employing a STEM IBL approach with interactive simulation to instil critical thinking skills apart from achieving academic goals. The integral approach of IBL, such as critical thinking, decision-making, problem-solving, communication, collaboration, and creativity, can promote HOTS in the classroom (MOE, 2016b), which is recommended as the 21st-century pedagogy (Chu et al., 2017).

Theoretical Framework

The developmental research of the SSQP-STEM Instructional Module is guided by Richey and Klein (2007) in conducting the design and development research, dividing the process into three phases: The needs analysis phase, the design and development phase, and the evaluation phase, as shown in Figure 1. The needs analysis is guided by the discrepancy model of Mckillip (1987), which perceives identifying problems by comparing the reality and the expectation in determining the existence of discrepancy (Mckillip, 2011).

For the design and development of the SSQP-STEM Instructional Module, the constructivism theory scaffold the teaching and learning approach, which embraces Bruner's perspective of 'learning by doing' and emphasises active learning with student-based learning while teachers conduct the instruction as a facilitator (Bruner, 1966; Soloway et al., 1996). The TABA Model (Klohr, 1963; Taba, 1962) determines the SSQP-STEM Instructional Module components and its organisation and employs the integrated STEM education approaches (Bybee, 2013; Morrison**,** 2006) with the IBL (Dewey, 1933) as the strategy for the L&F of the QP that is structured based on the 5E Instructional Model (Bybee, 2006) to sequence the learning activities.

In the final stage of the research, the TUP model of Bednarik (2002) determines the evaluation themes, which is in the form of a checklist in assessing the aspects of technological application, usability and the pedagogy applied in the SSQP-STEM Instructional Module.

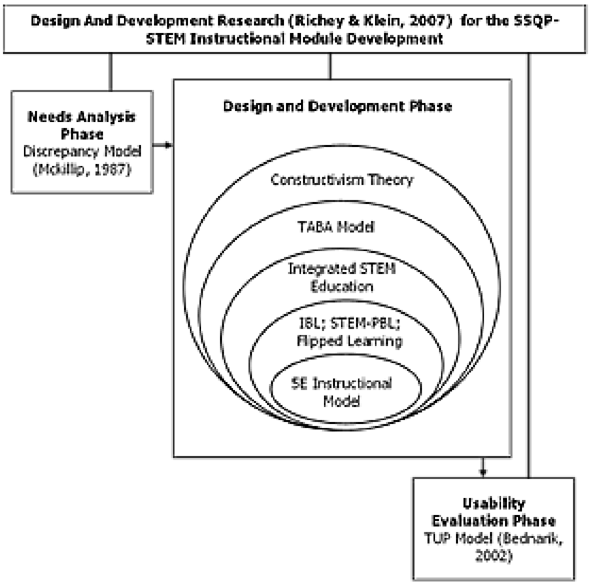

Figure 1. The Theoretical Framework

Conceptual Framework

The DDR phases (Richey & Klein, 2007) are followed to systemise the development of the instructional module. Figure 2 shows the conceptual framework, presenting the process that begins with the needs analysis study. Mckillip's (1967) conception of the needs analysis is the key to identifying the discrepancies and problems in the QP L&F based on the Discrepancy Model (DM). The findings obtained from the need analysis provide crucial information in determining the development of a practical instructional module for physics teachers. The constructivist theory based on the views of Bruner (1933) and Soloway et al. (1996) scaffold the teaching and learning approach, which supports the integrated STEM education perspectives and the IBL strategy in conducting the teaching and learning in the 21st-century era.

Taba's conception of her curriculum model development, the TABA Model (TM), guides the components selection and organisation of the SSQP-STEM Instructional Module. Taba emphasises the importance of an effective and meaningful learning strategy (Lunenburg, 2011; Taba, 1962), and for that, the integrated STEM education approach is conducted with the IBL strategy and the 5E Instructional Model as a guide to structure the learning activities to instil the STEM education elements: knowledge, skills and values (MOE, 2016; Thibaut et al., 2018). The validation of the components and elements of the instructional module is carried out through experts' consensus under the Fuzzy Delphi Method (FDM). Whereas the final phase, the evaluation phase, follows the TUP Model initiated by Bednarik (2002) to evaluate the instructional module's usability by obtaining the satisfaction level of physics teachers in terms of technological, usability and pedagogical aspects through the modified Nominal Group Technique (mNGT).

As the literature study patronage the research in developing the SSQP-STEM Instructional Module and provide crucial information to the design and development research (Rocco & Plakhotnik, 2009), it helps in establishing a framework for data collection, analysis, and methods in detail, such as philosophical views on what constitutes knowledge claims, general and specific research procedures (Creswell, 2015). The existing literature also provides a practical grounding for this developmental research's philosophical inputs (Creswell, 2015; Rocco & Plakhotnik, 2009).

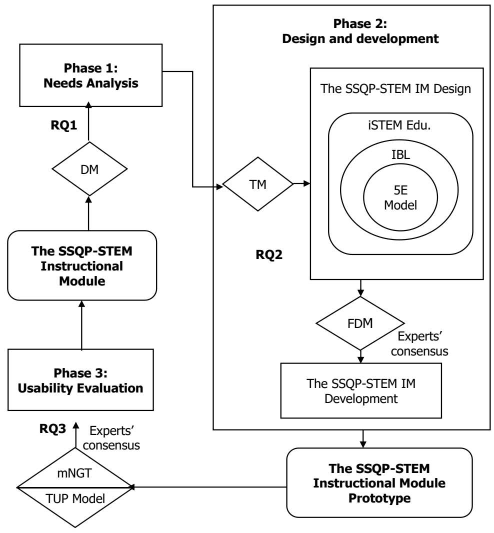

Figure 2. The Conceptual Framework

IV. METHOD

The development of the SSQP-STEM Instructional Module is carried out using the Fuzzy Delphi Method (FDM). It is a modified version of the classical Delphi technique that is more efficient in solving problems or fuzziness of certain problems (Mohd Ridhuan, 2016; Saffie et al., 2017). The FDM was developed through the integration of the fuzzy theory and the classical Delphi Method to improve the vagueness of the classical Delphi Method (Saffie et al., 2017), which is proven by Hsu et al. (2010) to be capable of solving the fuzziness in obtaining experts' consensus during the decision-making process.

Research instrument and data collection

A questionnaire with seven points Likert scale is used in this research for data collection. The questionnaire has six constructs, including the expert's demography as the first construct. The other five constructs are components of the instructional module derived from the TABA Curriculum Model, while the elements of each component were constructed from the physics *DSKP* and through a systematic literature review. The FDM questionnaire comprises 103 elements for the five components of the instructional module: learning outcomes, learning content, learning activities, instructional tools and learning evaluation.

Three experts in DDR and FDM carried out the face validity to ensure the questionnaire was suitable to measure experts' consensus on the components and elements of the instructional module before it was distributed to the experts.

The questionnaire was distributed individually via email for data collection. Several experts preferred to discuss while reviewing the instructional module, and it was conducted using an online platform using Google meet application and a face-to-face meeting. The data collected was then keyed into the Microsoft Excel software for data analysis.

The instrument's reliability was obtained by analysing 16 experts' responses to measure the questionnaire's internal consistency, assisted by IBM SPSS V28. Based on the analysis result, the questionnaire with 103 items and Cronbach's Alpha, α = 0.987, is reliable in measuring experts' consensus to validate the instructional module.

TABLE 1: RELIABILITY STATISTIC FOR THE FDM QUESTIONNAIRE

Cronbach's Alpha	Number of Items
0.987	103

Sampling and selection of professional experts

Adler and Ziglio (1996) recommended the number of experts in the Delphi technique from 10 to 15 persons, while Rowe and Wright (2001) suggested 5 to 20 persons, provided that they are qualified for the study field. Meanwhile, Jones and Twiss (1978) suggested that the number of experts in the Delphi technique should be between 10 and 50 persons. It shows no exact number of experts in carrying out FDM. However, scholars concern more on the depth of knowledge, experience, and quality of the chosen expert. Nworie (2011) justified that knowledge in the subject area is crucial in the Delphi study as the data collected depends on these experts' opinions to determine the level of consensus, the potential implications, or the possible outcome.

Scholars define an expert as a highly-skilled person with extensive knowledge and experience in a specific study (Dalkey & Helmer, 1963; Swanson & Falkman, 1997) and considered competent if they have been in practice consistently for more than five years (Berliner, 2004). Hence, for this study, 16 experts were chosen based on their professional knowledge in physics education, including experts in QP with more than five years of experience in the research field.

Data analysis

Data analysis in the Fuzzy Delphi method (FDM) uses the Triangular Fuzzy Number and the Defuzzification process (Ho & Wang, 2008; Mohd Ridhuan Mohd Jamil et al., 2019; Mohd Ridhuan Mohd Jamil & Nurulrabihah Mat Noh, 2020). The Triangular Fuzzy Number consists of m_1, m_2, and m_3, where m_1 represents the smallest value, m_2 represents the most plausible value, and m_3 refers to the maximum value of a fuzzy event. The three values in this Triangular Fuzzy Number are shown in Figure 3, a graph of the mean triangle against triangular values. It also represents the values of Triangular Fuzzy Numbers in the range of 0 to 1.

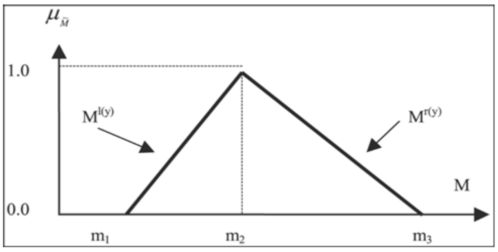

Figure 3. Triangular Fuzzy number

The Triangular Fuzzy Number emphasises two conditions that must be fulfiled to determine the experts' consensus on the components and elements of the instructional module. The first condition identifies the threshold value (d), while the second condition determines the acceptance percentage for each construct and item reviewed by the experts (Ho & Wang, 2008; Saedah Siraj; Muhammad Ridhuan Tony Lim Abdullah; Rozaini Muhammad Rozkee, 2020).

Meanwhile, the defuzzification process determines the ranking of the accepted items, whereby the item with the highest defuzzification value is considered the most important element in the component. However, this study focuses on identifying the accepted elements for the instructional module's components and determining if the element is necessary for the instructional module (Saedah Siraj; Muhammad Ridhuan Tony Lim Abdullah; Rozaini Muhammad Rozkee, 2020). Three formulas used to calculate the fuzzy score in the defuzzification process are as follows:

i. $A_{max} = 1/3 * (a_1 + a_m + a_2)$
ii. $A_{max} = 1/4 * (a_1 + 2a_m + a_2)$
iii. $A_{max} = 1/6 * (a_1 + 4a_m + a_2)$

The analysis procedure is conducted as follows:

Step 1: The linguistic variables of seven points of the Likert scale are translated into a triangular fuzzy number (Hsieh et al., 2004). Table 2 shows each seven-point Likert scale linguistic variable with the respected fuzzy scale values. In determining the fuzzy scale, the fuzzy number, r_{ij} is calculated using a formula $r_{ij} = \frac{1}{K}(r_{ij}^1 \pm r_{ij}^2 \pm r_{ij}^K)$, where $i = 1,2 \dots, m; j = 1,2 \dots, n; k = 1,2 \dots, k$.

TABLE 2: THE SEVEN POINTS OF THE LINGUISTIC VARIABLE

Linguistic variable	The fuzzy scale (m_1, m_2, m_3)
Strongly disagree	(0.0, 0.0, 0.1)
Disagree	(0.0, 0.1, 0.3)
Somewhat disagree	(0.1, 0.3, 0.5)
Neither agree nor disagree	(0.1, 0.3, 0.5)
Somewhat agree	(0.0, 0.1, 0.3)
Agree	(0.3, 0.5, 0.7)
Strongly agree	(0.0, 0.1, 0.3)

Step 2: The data analysis process continues by calculating the threshold value, d using a formula:

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]}$$

From the formula, m_1, m_2 and m_3 are the average fuzzy value of experts' opinions, while n_1, n_2 and n_3 are the fuzzy values obtained from the respondent. The calculation of the threshold value, d determines the consensus level of experts, and this is the first predetermined condition to be complied with, whereby the threshold value, d must be less than or equal to 0.2 ($d \leq 0.2$) (Cheng & Lin, 2002) to achieve experts' consensus on the item.

Step 3: Next, the percentage of experts' consensus is calculated, and this is the second predetermined condition that must be achieved, whereby the percentage of the experts' consensus must be at least 75.0% (Chu & Hwang, 2008; Murry & Hammons, 1995).

Step 4: The final step of the data analysis is carried out by calculating the mean of the fuzzy number, which is the Defuzzification Process (Ariffin et al., 2018; Wan Nurul Huda Ab Kadir et al., 2019; Yaakob & Yusoff, 2017). The analysis is carried out to calculate the fuzzy score value (A). This analysis is the third predetermined condition to determine whether each item is acceptable. The fuzzy score value (A) must be higher than or equal to the median (α - cut) value of 0.5 to show that the experts accept the item (Ariffin et al., 2018; Saido et al., 2018). The fuzzy score (A) also determines the ranking of each item according to the experts' view. The formula selected to calculate the fuzzy score (A) is as follows: $A = (1/3) * (m1 + m2 + m3)$

Step 5: The items for every construct are then assessed based on the three predetermined conditions. This step determines the validity of the components and elements of the instructional module based on experts' consensus (Hsu et al., 2010; Mohamad et al., 2015).

The development of the instructional module prototype is based on the interpretation of the data obtained from the FDM analysis and the written feedback from the experts, which determine the validity of the components and elements of the instructional module.

V. FINDINGS

The SSQP-STEM Instructional Module comprises five components: learning objectives, learning content, learning activities, instructional tools and learning evaluation, with 103 elements for all components. These components and elements are presented in the questionnaire representing the module's content reviewed by the experts. Their responses to the questionnaire and comments will validate the SSQP-STEM Instructional Module prototype.

Learning objectives

Table 3 presents the result of the analysis of the threshold value, d, experts' consensus percentage and the fuzzy score, A, of each element for the learning objectives. The analysis shows that three out of 21 items were rejected due to their failure to meet one or more of the predetermined conditions. The analysis also presents the ranking of each item, which determines the level of acceptance of the elements for the learning objectives of the instructional module (Saedah Siraj; Muhammad Ridhuan Tony Lim Abdullah; Rozaini Muhammad Rozkee, 2020). For instance, item 10 received the highest voting, which most agreed by the experts that problem-solving related to photons could be achieved by giving a formative practice with problem-solving questions. The rest of the items were accepted except items 5, 6 and 8. These rejected items were eliminated from the learning objective and replaced using experts' suggestions.

TABLE 3: ANALYSIS RESULT FOR LEARNING OBJECTIVES' ELEMENTS

Item	Triangular Fuzzy Numbers		Defuzzification Process				Experts' consensus	Items accepted for ranking	Ranking
	Threshold value, d (≤ 0.2)	% of experts' consensus (≥ 75%)	m1	m2	m3	Fuzzy score (A) (α-cut ≥ 0.5)			
1	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	2
2	0.084	94%	0.763	0.925	0.994	0.894	ACCEPTED	0.894	10
3	0.089	88%	0.738	0.906	0.988	0.877	ACCEPTED	0.877	11
4	0.089	94%	0.775	0.931	0.994	0.900	ACCEPTED	0.900	7
5	0.209	63%	0.650	0.825	0.931	0.802	REJECTED		
6	0.180	63%	0.663	0.844	0.944	0.817	REJECTED		
7	0.169	81%	0.725	0.881	0.956	0.854	ACCEPTED	0.854	17
8	0.171	63%	0.675	0.850	0.950	0.825	REJECTED		
9	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	2
10	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	1
11	0.089	88%	0.738	0.906	0.988	0.877	ACCEPTED	0.877	12
12	0.126	81%	0.700	0.875	0.969	0.848	ACCEPTED	0.848	18
13	0.066	100%	0.763	0.931	1.000	0.898	ACCEPTED	0.898	8
14	0.070	88%	0.713	0.894	0.988	0.865	ACCEPTED	0.865	14
15	0.108	88%	0.775	0.925	0.988	0.896	ACCEPTED	0.896	9
16	0.141	75%	0.750	0.900	0.975	0.875	ACCEPTED	0.875	13
17	0.072	100%	0.775	0.938	1.000	0.904	ACCEPTED	0.904	5
18	0.089	94%	0.775	0.931	0.994	0.900	ACCEPTED	0.900	6
19	0.097	81%	0.713	0.888	0.981	0.860	ACCEPTED	0.860	16
20	0.112	88%	0.725	0.894	0.975	0.865	ACCEPTED	0.865	14
21	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	4

Learning content

The learning content component contains 13 elements determined based on the analysis of the *DSKP* and literature review. The analysis for the learning content shows that all items or elements are accepted with the threshold value, d below 0.2, average experts consensus percentage of 92% and fuzzy score, A above 0.5, as presented in Table 4. Based on the ranking analysis, item 11 ranked at the lowest level while item 6 ranked the highest. Overall, all learning content elements are accepted and suitable for teaching secondary school QP.

TABLE 4: ANALYSIS RESULT FOR LEARNING CONTENT ELEMENTS

Item	Triangular Fuzzy Numbers		Defuzzification Process				Experts' consensus	Items Accepted for ranking	Ranking
	Threshold value, d (≤ 0.2)	% of experts' consensus (≥ 75%)	m1	m2	m3	Fuzzy score (A) (α-cut ≥ 0.5)			
1	0.084	94%	0.763	0.925	0.994	0.894	ACCEPTED	0.894	8
2	0.110	88%	0.788	0.931	0.988	0.902	ACCEPTED	0.902	5
3	0.075	100%	0.788	0.944	1.000	0.910	ACCEPTED	0.910	2
4	0.076	94%	0.750	0.919	0.994	0.888	ACCEPTED	0.888	9
5	0.076	94%	0.750	0.919	0.994	0.888	ACCEPTED	0.888	9
6	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	1
7	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	4
8	0.066	100%	0.763	0.931	1.000	0.898	ACCEPTED	0.898	6
9	0.075	100%	0.788	0.944	1.000	0.910	ACCEPTED	0.910	2
10	0.108	88%	0.775	0.925	0.988	0.896	ACCEPTED	0.896	7
11	0.181	75%	0.700	0.863	0.950	0.838	ACCEPTED	0.838	13
12	0.105	81%	0.725	0.894	0.981	0.867	ACCEPTED	0.867	12
13	0.124	81%	0.763	0.913	0.981	0.885	ACCEPTED	0.885	11

Learning activities

The learning activities component comprises 23 elements designed for QP lessons based on systematic literature review and document analysis findings. The experts' consensus for the learning activities shows that all items are accepted with the threshold value, d below 0.2, experts' average consensus percentage of 91% and fuzzy score, A above 0.5, as presented in Table 5. Based on the ranking analysis, item 20 ranked at the lowest level while item 23 ranked the highest. All learning content elements are accepted and suitable for secondary school QP. The item analysis will be discussed further in the following section.

TABLE 5: ANALYSIS RESULT FOR LEARNING ACTIVITIES' ELEMENTS

Item	Triangular Fuzzy Numbers		Defuzzification Process				Experts consensus	Items Accepted for ranking	Ranking
	Threshold value, d	% of experts' consensus (≥ 75%)	m_1	m_2	m_3	Fuzzy score (A) (α-cut ≥ 0.5)			
1	0.095	94%	0.738	0.906	0.981	0.875	ACCEPTED	0.875	20
2	0.084	94%	0.763	0.925	0.994	0.894	ACCEPTED	0.894	12
3	0.097	88%	0.750	0.913	0.988	0.883	ACCEPTED	0.883	15
4	0.089	88%	0.738	0.906	0.988	0.877	ACCEPTED	0.877	18
5	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	4
6	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	5
7	0.072	100%	0.775	0.938	1.000	0.904	ACCEPTED	0.904	10
8	0.110	88%	0.788	0.931	0.988	0.902	ACCEPTED	0.902	11
9	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	3
10	0.097	88%	0.750	0.913	0.988	0.883	ACCEPTED	0.883	15
11	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	5
12	0.104	88%	0.763	0.919	0.988	0.890	ACCEPTED	0.890	14
13	0.123	75%	0.713	0.881	0.975	0.856	ACCEPTED	0.856	22
14	0.089	88%	0.738	0.906	0.988	0.877	ACCEPTED	0.877	18
15	0.084	94%	0.763	0.925	0.994	0.894	ACCEPTED	0.894	13
16	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	8
17	0.119	81%	0.750	0.906	0.981	0.879	ACCEPTED	0.879	17
18	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	9
19	0.143	81%	0.738	0.894	0.969	0.867	ACCEPTED	0.867	21
20	0.116	75%	0.700	0.875	0.975	0.850	ACCEPTED	0.850	23
21	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	5
22	0.086	94%	0.825	0.956	0.994	0.925	ACCEPTED	0.925	2
23	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	1

Instructional tools

The instructional tools component contains 25 elements from the systematic literature review and the needs analysis findings determined for QP lessons. The experts' consensus for the instructional tools shows that all items are accepted with the threshold value, d below 0.2, experts' average consensus percentage of 97% and fuzzy score, A above 0.5, as presented in Table 6. Based on the analysis, item 2 ranked the lowest while item 13 ranked the highest, determining the experts' lowest and highest acceptance of the instructional tools in facilitating QP teaching and learning. All elements are accepted and suitable to be applied in teaching QP.

TABLE 6: ANALYSIS RESULT FOR INSTRUCTIONAL TOOLS' ELEMENTS

Item	Triangular Fuzzy Numbers		Defuzzification Process				Experts' consensus	Items accepted for ranking	Ranking
	Threshold value, d (≤ 0.2)	% of experts' consensus (≥ 75%)	m_1	m_2	m_3	Fuzzy score (A) (α-cut ≥ 0.5)			
1	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	9
2	0.110	88%	0.788	0.931	0.988	0.902	ACCEPTED	0.902	25
3	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	3
4	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	9
5	0.110	88%	0.788	0.931	0.988	0.902	ACCEPTED	0.902	24
6	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	5
7	0.066	100%	0.838	0.969	1.000	0.935	ACCEPTED	0.935	1
8	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	21
9	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
10	0.075	100%	0.788	0.944	1.000	0.910	ACCEPTED	0.910	20
11	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
12	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	17
13	0.066	100%	0.838	0.969	1.000	0.935	ACCEPTED	0.935	1
14	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	5
15	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
16	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	21
17	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
18	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	17
19	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	9
20	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	3
21	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	21
22	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	17
23	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	5
24	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
25	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	5

Learning evaluation

The learning evaluation component contains 21 elements of method and activities selected to assess students' performance for every lesson in the instructional module, generated from the systematic literature review and the document analysis findings. The experts' consensus for the learning evaluation shows that all items are accepted with the threshold value, d below 0.2, experts' average consensus percentage of 96% and fuzzy score, A above 0.5 for each item, as presented in Table 6. Based on the ranking analysis, item 4 ranked at the lowest level while item 21 ranked the highest. All elements are accepted and suitable for assessing students' performance.

TABLE 7: ANALYSIS RESULT FOR LEARNING EVALUATION ELEMENTS

Item	Triangular Fuzzy Numbers		Defuzzification Process				Experts' consensus	Items accepted for ranking	Ranking
	Threshold value, d (≤ 0.2)	% of experts' consensus (≥ 75%)	m_1	m_2	m_3	Fuzzy Score (A) (α-cut ≥ 0.5)			
1	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	10
2	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	6
3	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	15
4	0.089	94%	0.775	0.931	0.994	0.900	ACCEPTED	0.900	21
5	0.086	94%	0.825	0.956	0.994	0.925	ACCEPTED	0.925	4
6	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	1
7	0.092	94%	0.788	0.938	0.994	0.906	ACCEPTED	0.906	20
8	0.075	100%	0.788	0.944	1.000	0.910	ACCEPTED	0.910	18
9	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	6
10	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	14
11	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	6
12	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	15
13	0.086	94%	0.825	0.956	0.994	0.925	ACCEPTED	0.925	4
14	0.075	100%	0.813	0.956	1.000	0.923	ACCEPTED	0.923	6
15	0.110	88%	0.800	0.938	0.988	0.908	ACCEPTED	0.908	19
16	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
17	0.090	94%	0.813	0.950	0.994	0.919	ACCEPTED	0.919	10
18	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	1
19	0.076	100%	0.800	0.950	1.000	0.917	ACCEPTED	0.917	12
20	0.092	94%	0.800	0.944	0.994	0.913	ACCEPTED	0.913	15
21	0.072	100%	0.825	0.963	1.000	0.929	ACCEPTED	0.929	1

VI. DISCUSSION

This study is in phase 2 of the developmental research of the SSQP-STEM Instructional Module, which was conducted to validate the components and elements of the module using FDM. It has answered the research questions as follows:

i. Are the SSQP-STEM Instructional Module learning objectives appropriate based on expert consensus?
ii. Are the SSQP-STEM Instructional Module learning contents appropriate based on expert consensus?
iii. Are the instructional strategies and the learning activities for the SSQP-STEM Instructional Module appropriate based on expert consensus?
iv. Are the SSQP-STEM Instructional Module instructional tools appropriate based on expert consensus?
v. Are the learning evaluations for the SSQP-STEM Instructional Module appropriate based on expert consensus?

Based on the findings, the study has achieved expert consensus, with several corrections and adjustments to the three rejected items. Table 8 briefly describes the amendment for the eliminated items from the learning objectives component. This amendment also involves correcting item 11 in the learning content, which received the lowest acceptance among experts. This item refers to the wave-particle duality concept and the derivation of its formula that is found insufficient to explain the concept according to the QP experts in the study. Two items for instructional tools were removed as experts found them confusing and replaced with other materials suggested by the experts, as stated in Table 8. The findings also confirm that most of the elements of the SSQP-STEM Instructional Module are appropriate for the teaching and learning of QP at the secondary school level. With the experts' consensus, the SSQP-STEM Instructional Module is validated as a prototype that will go through usability evaluation in the final phase of this study.

TABLE 8: AMENDMENT FOR THE ELIMINATED ITEMS

Item	Learning Objective	Amendment
5	A student can explain wave-particle duality by investigating microscopic particles' behaviour through a double-slit experiment from the PhET Quantum Wave interactive simulation	• The simulation is eliminated • A video suggested by Expert 1 is used to replace the simulation. • Questions for stimulating inquiry are adjusted to elicit students' ideas better. • The learning outcomes will be adjusted by stating the specific definitions of the wave-particle duality concept.
6	A student can explain wave-particle duality by deriving de Broglie wavelength	• The expert shared a QP reference and explained the proper derivation of the de Broglie wavelength formula. The module will be updated by referring to the guidance of the expert.
8	A student can explain the concept of the photon by understanding the analogy between a ball and a pit	• The pit and ball analogy is eliminated and replaced with a diagram explaining the energy transfer between photon and electrons by referring to the expert's suggestion to explain the photon using the photoelectric effect.

The SSQP-STEM Instructional Module is created to assist physics teachers in conducting QP lessons with integrated STEM education approaches that include IBL, flipped classroom and STEM-PBL strategies to create a student-centred learning environment by providing learning activities with instructional tools that facilitate teachers in teaching meaningful QP lessons with integrated STEM education approach. Studies have shown that these learning strategies are effective in motivating students to construct their own knowledge, fostering skills and values as highlighted in the STEM education's approach (Abdurrahman et al., 2019; Ardianti et al., 2020b; Parno et al., 2021; Parno, Yuliati, Munfaridah, Ali, Indrasari, et al., 2020; Permana et al., 2021; Yuliati, Parno, Yogismawati, et al., 2018).

Prior studies also show that STEM-based modules enhanced students' attitudes, knowledge, and skills competencies and raised their motivation to learn science and mathematics (Abdurrahman et al., 2019; Benek & Akcay, 2022; Fan et al., 2018; Morris et al., 2021; Parno, Yuliati, Munfaridah, Ali, Rosyidah, et al., 2020b). Besides, STEM-based learning can potentially assist their future success in STEM-related fields careers (Hu et al., 2020; Schmidt & Fulton, 2016; Teo, 2019; Toma & Greca, 2018). Hence, with the development of this module, it is hoped to serve its purpose of facilitating physics teachers in conducting the instructions with the emphasis on the STEM education elements in their QP lessons.

VII. CONCLUSION

The development of the SSQP-STEM Instructional Module is an effort to assist physics teachers in conducting meaningful QP lessons, a new topic in the physics curriculum that is identified as a challenging topic due to its abstractness and confusing theory. It is also developed to support the ministry of education's aspiration to foster the critical skills and values needed in developing human capital by integrating the STEM education approach into the teaching and learning activities. The experts' views and assessment of the instructional module are crucial to ensure the components and elements of the module are suitable, relevant and serve their purpose. The FDM has systemised the module's development by providing a systematic procedure for collecting and analysing the data with the predetermined conditions that can guarantee the study achieves the consensus among experts and thus validate the module prototype. It is hoped that the SSQP-STEM Instructional Module will be useful in facilitating teachers and increasing the quality of students' learning and attitude towards physics, especially QP. Therefore, this study is optimistic that in pursuing a successful transformation of the education system, it begins by improving the teaching and learning quality through active and student-centred learning, focusing on connecting learning with real-world scenarios as to how the instructional module is developed. Nonetheless, significant efforts, particularly from teachers, are required to assure the success of the initiative.

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