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A Needs Analysis Study in Developing Quantum Physics Instructional Module for Secondary School With an Integrated Stem Education Approach

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Abstract. Effective instructional strategies have been highlighted in teaching Quantum physics (QP) since this topic is theoretically complex and different from classical physics. In addressing this issue, a needs analysis (NA) was carried out to identify the anticipated challenges in QP learning and facilitation (L&F) and the integration of STEM education in a physics classroom. This research is a qualitative study where a semi-structured interview was conducted with two experts in physics education and two physics teachers selected under a purposive sampling approach. The interview was one-on-one through online platforms, held during the Covid-19 pandemic's mobility control order (MCO). The data from the semi-structured interview was analysed using thematic analysis, and the findings were presented as thematic maps. Two major themes emerged from the thematic analysis: 1) the expectation in QP L&F based on experts' and teachers' views and 2) the discrepancies in SSQP-STEM L&F gathered from the teachers' opinions and perspectives. The first theme denotes 1.1) teachers' professional development, 1.2) pedagogical content knowledge, 1.3) instructional strategy, and 1.4) QP L&F resources. The second theme describes the discrepancies of SSQP-STEM L&F in terms of 2.1) QP nature, 2.2) insufficiency of resources in QP L&F, and 2.3) teachers' perceptions of students' characteristics in the physics classroom, and 2.4) the teachers' competencies issues in teaching QP. Overall, the finding shows that a practical instructional module needs to be developed to cater to the physics teachers' demands.

Keywords: Instructional module, Needs analysis, Secondary school, STEM education, Quantum Physics

INTRODUCTION

This paper discusses the needs analysis (NA) phase on developing a secondary school level instructional module for QP using an integrated STEM education approach. The NA study is carried out to identify the extent of an instructional module is needed in teaching and learning QP. In particular, this study aims to identify the teachers' challenges in QP's learning and facilitation (L&F) and expectations in designing a practical instructional module for QP.

This developmental study employs the design and development research (DDR) (Richey & Klein, 2007) that begins with the NA phase to identify the needs of an instructional module for secondary school QP. This step was conducted as a tool for decision-making (Mckillip, 2011) in creating a practical instructional module for QP with an integrated STEM education approach. In particular, it was an effort to obtain experts' views on appropriate instructional approaches and strategies and gain insight into how QP and STEM education can be integrated. Besides, it allows the researcher to discover physics teachers' anticipated problems and needs in teaching QP with integrated STEM education.

Wave-particle duality and the photoelectric effect are fundamental topics in QP for the secondary school level (Krijtenburg-Lewerissa et al., 2018) that require teachers to plan a practical instruction to guide students in constructing their understanding of the nature of light and matter and the concept of a photon (McKagan et al., 2007; Supurwoko et al., 2017) and address the gap between classical and quantum concepts of waves, particles, and uncertainty by emphasising their differences in the classical and quantum world (Rodriguez, 2018).

However, the QP topics have been deemed challenging due to the abstract nature of the concepts and their reliance on qualitative reasoning and mental models (Malgieri et al., 2017; McKagan et al., 2008). Research showed that it is challenging for teachers to deliver this topic (Bouchée et al., 2021; Bungum et al., 2015; Stadermann & Goedhart, 2020) and even doubted its worth being taught at the secondary school level (Moraga-Calderón et al., 2020). As a result, it caused misconception and disinterest among students (Kohnle et al., 2014; McKagan et al., 2007; Supurwoko et al., 2017).

Therefore, the effectiveness of instructional strategies and tools are core aspects that must be emphasised to address the issues in L&F of QP topics (Bungum et al., 2015; McKagan et al., 2009). Besides, the instructional materials' availability influences teachers' readiness to teach this topic as it is newly added to the Malaysian secondary school physics syllabus (Sungkim et al., 2021).

In designing the instructional module, the integrated STEM education approach was employed to instil active and meaningful QP learning, which is also highlighted in the current education setting (Bunyamin, 2015; Shahali et al., 2015; Amelia & Lilia Halim, 2019). It aims to guide teachers in highlighting the critical elements emphasised in STEM education in the learning activities, as many are still struggling to practice them in science classrooms (Amelia & Lilia Halim, 2019; Markus et al., 2021; Nur Farhana Ramli & Othman Talib, 2017).

In the following sections, the theoretical and conceptual framework is presented to clarify the foundation and the research process in designing and developing the instructional module for the secondary school QP with an integrated STEM education approach. This paper also discusses the research methodology and the findings of the NA study.

THEORETICAL FRAMEWORK

The theoretical framework of this research is described in three phases following the DDR approach, as shown in Figure 1. The NA was guided by the discrepancy model (DM) (McKillip, 1987). This model was adapted to guide the process in identifying the gap and the anticipated problems related to QP L&F, which involves three phases. It starts with setting up a goal in identifying what ought to be or the expectation in QP L&F. Next, performance analysis is carried out to determine the actual situation or condition of the instructional environment of the physics classroom. The third phase of the study was discrepancy identification, which involves identifying gaps between what is and what should be. The discrepancy is also called problems that require specific solutions (McKillip, 2011). "Need" is then indicated when the evaluated performance is lower than desired (McKillip, 2011).

Several theories or models were applied to guide the Secondary School Quantum Physics-STEM (SSQP-STEM) Instructional Module's design in the design and development phase. The constructivism theory scaffolds the instructional and learning approach, while the TABA Model (TM) (Taba, 1962) is adapted to structure and organise the components and elements of the instructional module. The integrated STEM education is the main component of the instructional approach that includes STEM education elements practices and STEM project-based learning (STEM PBL). This approach emphasised inquiry-based learning (IBL) as a pedagogical strategy and the 5E Instructional Model (Bybee et al., 2006) as an organiser in structuring the learning activities for the QP L&F.

The TM denotes seven stages in curriculum design (Aydın et al., 2017; Lunenburg, 2011). It can be an iterative or a cycle process that educators or teachers can apply in designing a curriculum (Lunenburg, 2011). This study follows all the TM stages that begin with diagnosing the needs gathered based on teachers' perceptions in the NA phase. It then identifies learning objectives from the secondary school QP learning standard. In the third stage, instructional content was selected based on the content standard provided by the ministry of education. Fourth, the content was then organised through an inductive approach, where students discover QP knowledge by exploring related applications or situations before constructing their knowledge of the QP concepts.

The instructional contents were organised with appropriate learning activities using the 5E Instructional Model. In the fifth stage, the learning experiences are determined by selecting instructional methods obtained from experts' views and literature where integrated STEM education approach and IBL strategy are employed for QP L&F. It was organised for the learning experience using the 5E Instructional Model. In the final stage, Taba emphasised the importance of determining what to evaluate and how to evaluate the curriculum to assess its effectiveness (Portillo et al., 2020). Thus, the instructional module is carefully designed to ensure the learning objectives are synced with the evaluation method and purposes.

In the final phase of the research, the TUP model (Bednarik, 2002) guides the module usability evaluation. This model is used as a guideline in assessing learning products or materials in a learning environment that applies technology. Bednarik et al. (2004) justified that usability and pedagogy are dependent upon the technological aspects, whereby the use scenario determines the applicability of these three aspects, whether a particular feature suits its actual purpose. It is a tool that comprises a checklist classified into three sections; technology, usability, and pedagogy, which are in questions format. Considering each question in the checklist has been tested for validity and reliability, researchers or educators can conduct a usability evaluation by themselves (Amani Dahaman, 2014; Bednarik et al., 2004).

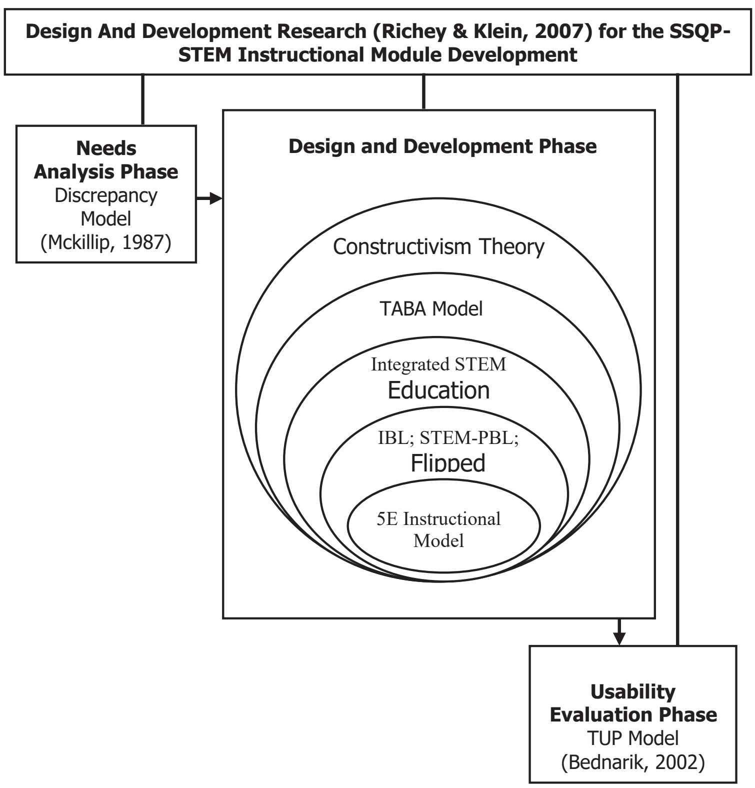

Figure 1 Theoretical framework diagram of the SSQP-STEM Instructional Module development

CONCEPTUAL FRAMEWORK

The conceptual framework in Figure 2 illustrates a systematic process according to the DDR approach as a framework of this research. The framework links the concepts and relevant theories in a progressive order to systematise the SSQP-STEM Instructional Module's development.

Mckillip's (1967) conception of the NA is the key concept in identifying the discrepancies or problems in the QP L&F. The findings obtained from the NA provides crucial information in designing a practical instructional module for physics teachers.

In the following phase, Taba's conception of the curriculum model development guides the organisation and the sequence of the instructional module content. The integrated STEM education is the pedagogical approach that applies the IBL strategy complemented with the 5E Instructional Model to promote critical thinking and science process skills. Experts will validate the module's design through the Fuzzy Delphi Method (FDM) to obtain their consensus (Lin, 2013; Saffie et al., 2017) in developing the module prototype.

The evaluation phase in the final stage adapts the TUP Model initiated by Bednarik (2002) to evaluate the instructional module's usability. The modified Nominal Group Technique (mNGT) is employed to obtain experts' consensus (Dobbie et al., 2004; Mazidah et al., 2018) on the module usability in finalising the SSQP-STEM Instructional Module.

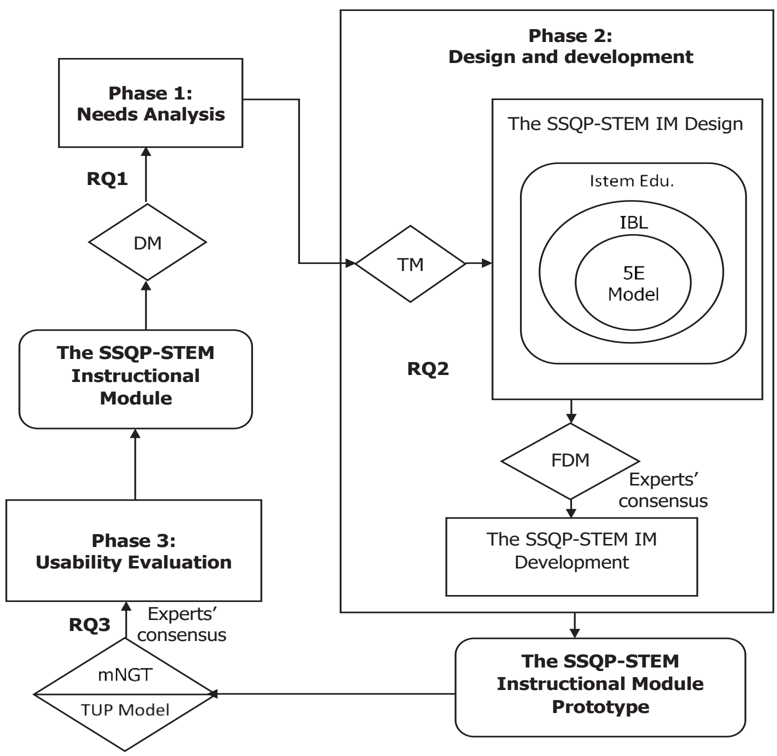

Figure 2 The conceptual framework for the SSQP-STEM Instructional Module development

METHODOLOGY

The NA study is qualitative and uses a semi-structured interviews protocol for data collection. This method is used to obtain the experts' and teachers' perspectives on QP L&F in secondary schools.

The semi-structured interview was chosen because it allows in-depth exploration of a detailed data collection on the research participants' experiences and feelings (Galletta, 2013). Through interviews, the researcher may more readily observe and probe into the study participants' attitudes, interests, feelings, things that needed their attention, and values (Merriam, 1998). This method is suitable for a needs analysis study as it can assist the researcher in identifying the underlying reason for an existing problem, and with the data gathered, the researcher can take the necessary action to solve the problem (McKillip, 2016). Because the NA phase is critical for determining the design and development phase that follow (Richey et al., 2004), the researcher used this method to explore and identify issues pertaining to physics L&F. In supporting the information given by the informants, document analysis is triangulated with the data to corroborate the information given by research participants.

Sampling. Qualitative sampling focuses on the quality and is influenced by the saturation of the data collected; as being said, the research samples should be large enough to allow for a novel and fully detailed knowledge of the phenomenon being studied, yet small enough that an excessive number of samples does not hamper in-depth, case-based research of qualitative data (Sandelowski, 1995).

For that reason, the sample size for this study is determined by the saturation of data collected from participants, which is subsequently achieved by ensuring that the sample size is large enough to repeat the data sorting within every item (Denzin & Lincoln, 2018). Besides, saturation is the principle frequently used to estimate sample size and assess qualitative data sufficiency (Konstantina Vasileiou et al., 2018). The data saturation principle is based on Guba and Lincoln (1985), where the sample size is governed by the informational redundancy criteria, which states that sampling may end when no new information is elicited. It is also supported by Malterud et al. (2016), who established information power as a pragmatic guiding principle, arguing that the more information power a sample has, the smaller the sample size required, and vice versa.

Although there is no transparent data for determining the sampling size in qualitative interview studies (Malterud et al., 2016), Creswell (2015) has suggested that the ideal number of qualitative participants is 1 to 3 or 30 to 50 people depending on the depth of the study. Since this NA study focuses on identifying the extent of the QP instructional module is needed among physics teachers and obtaining the experts' views on a practical instructional module for QP with integrated STEM education, four participants were selected using purposive sampling (Creswell, 2015) with the confidence that they are information-rich in the field of study (Michael Quinn Patton, 2014), which is measured based on their qualification, achievement and experiences in physics education. This study selected two physics education experts, lecturers from *Institut Pendidikan*

Guru (IPG) in Sabah and two physics teachers with more than five years of teaching experience in physics from Sabah as research participants. The participants' selection is rather homogenous; however, the teachers' school background is different, one from daily secondary school and the other one is from boarding school. Experts and physics teachers are selected as informants because they can give information on the issues regarding SSQP-STEM L&F. Moreover, teachers can express their personal views on the topic and the ongoing issues, especially their needs to facilitate QP teaching and learning. Table 1 summarises the details of the research participants.

Table 1 Research participants in the NA study

Research participants	Age	Education background	Position	Experience in physics education
Lecturer 1	54	Master in Physics education	Physics lecturer	29 years
Lecturer 2	40	Master in Physics education	Physics lecturer	10 years
Teacher 1	40	Bachelor's Degree (Honors) in Electronic Physics	Physics teacher	14 years
Teacher 2	39	Bachelor's Degree (Honors) in Physics	Physics teacher	11 years

Data collection. This NA study employed a semi-structured interview as an instrument for data collection with document analysis to support the information gained (Cohen et al., 2007) in discovering the experts and teachers' views pertaining to QP L&F and the integration of STEM education. This method is chosen as it allows reciprocity between the interviewer and informants in probing responses (Galletta, 2013, p. 24) and enables the interviewer to improvise follow-up questions in response to the informant's responses to obtain in-depth information (Wengraf, 2001, p. 159). The interview protocol contained seven questions for the experts and nine questions for the teachers developed based on the literature review (Galletta, 2013). Four experts, including one expert for language translation, had reviewed and validated the interview protocol to determine the construct credibility in gathering information from the informants (Nowell et al., 2017; While & Barriball, 1994). The interview questions were piloted by interviewing two teachers to assess the appropriateness and preliminary recommendations about the research's viability (Galletta, 2013; While & Barriball, 1994). Besides, it provided training for the researcher in conducting semi-structured interviews and developing rapport with informants (Galletta, 2013). Notably, the pilot aided the researcher in preparing for the interview and a sense of conversation flow.

The interviews were then conducted via an online platform using Google Meet after appointments were fixed with the informants. The informants were informed about the interview's designated time, requiring at least 30 minutes (Whiting, 2008). However, the session depended on the informants' responses, and some sessions lasted more than an hour. The interviews were recorded to facilitate the researcher in the transcription process (Whiting, 2008). The transcripts were then returned to the informants to review and validate the information given (Whiting, 2008). The informants have provided documents such as lesson plans and articles related to the information given as a reference for the researcher in the data analysis and, most importantly, served for data triangulation to improve validity (Denzin & Lincoln, 2018) and credibility of the research findings (Guba & Lincoln, 1989; Nowell et al., 2017).

Data was also collected during the QP Expolarion Program organised by Sabah State Education Department on 27 – 28 September 2021. The researcher participated as a speaker to share the NA study and presented one of the lessons in the module. With the opportunity given, three open-ended questions were selected from the interview protocol given through the Padlet application for physics teachers to share their responses.

Data analysis. The data analysis process commences immediately after the data collection, which means the researcher has completed interviewing all participants in the study. The recorded interview is transcribed thoroughly without omitting anything that is heard. This procedure enables the researcher to go into each data and do a holistic review (Creswell, 2015). Once the data is transcribed, the researcher carried out the analysis by following the method of Braun and Clarke (2006) for thematic analysis.

Deductive thematic analysis was carried out as a technique for data analysis. The main themes were determined by familiarising key points from the theoretical framework, the Discrepancy Model (McKillip, 1987) and reflected in the interview questions (Terry et al., 2017) before a comprehensive analysis of the interview transcripts. However, the subthemes were identified after the codes' generation making this analysis a partially inductive approach. The subthemes were then collated and connected to relevant codes (Fereday & Muir-Cochrane, 2006). The coding development is inclined towards semantic orientation, whereby the information gathered is analysed with explicit meaning to form codes (Terry et al., 2017).

The data analysis was done manually, adapted from Braun and Clarke's (2006) six steps, as shown in Table 2, to produce the analysis outcomes. The literature review (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006; Merriman et al., 2021; Nowell et al., 2017; Scharp & Sanders, 2019; Terry et al., 2017) and expert guidance were employed to understand the process for each phase, ensuring that the thematic analysis is carried out correctly. The informants have reviewed and verified the interview transcripts before the analysis process to improve the data's trustworthiness (Nowell et al., 2017; Whiting, 2008). Findings from the analysis of the semi-structured interview were triangulated with document analysis and the open-ended questionnaire given through Padlet application during the QP Expolarion Program organised by Sabah State Education Department on 27 – 28 September 2021 that served as a base of the QP instructional module development for secondary schools.

Table 2 Thematic analysis phases in NA study for the SSQP-STEM Instructional Module development

No	Phase	Process
1	Familiarising data	• Listen and relistening carefully to the recorded interview • Transcribe the interview conversation • Read and re-read the transcribed data • Triangulate the data with documents shared by the informants
2	Generating initial codes	• Code the important points of the data systematically across the full data collection • Collate pertinent data for each code systematically in a table
3	Generating themes	• Collate codes into the initiated themes that were generated from the theoretical framework. • Connect the codes to the relevant theme • Identify subthemes and connect to related codes
4	Reviewing themes	• Check if the themes are appropriate with both the coded extracts and the whole data set • Generate a thematic 'map' of the analysis • Check the appropriateness of the codes and themes with the research experts
5	Defining and naming themes	• Keep analysing to fine-tune the specifics codes of each subtheme and the overall themes presented by the study • Generate clear definitions and names for each theme and subtheme
6	Producing report	• Finalise the analysis of selected extracts by relating them to the research questions and literature • Produce a scholarly report of the analysis

Table 3 presents the codes collated under the identified subthemes from the interview transcripts and themes generated from the Discrepancy model (McKillip, 1987). The data from Table 3 can be presented as a thematic map (Braun & Clarke, 2006) discussed in the finding section.

Table 3 The collation of the codes identified from the interview transcripts with the themes and subthemes

Themes/ Definition	Subtheme generated from the transcripts	Codes generated from the interview transcripts
The expectation in SSQP-STEM L&F • The expectation in the SSQP-STEM L&F refers to the anticipation of physics teachers' performance level and hope (Mckillip, 2011) in QP L&F with the integration of STEM education	Teachers' professional development	• In house training • Peer coaching • Self-learning • Continuing Professional Development
	Pedagogical Content Knowledge	• Poses QP knowledge from bachelor's degree education • Well-equipped with QP content and pedagogical skill • Versatile
	Instructional strategy	• Active learning • 21st-century learning style • Integrate ICT to QP L&F • Flipped classroom • Inquiry-based learning • Activity-based learning • STEM Project-based learning
	QP L&F resources	• Easy access to QP L&F materials • MOE should provide QP L&F materials • Internet • DidikTv KPM
Discrepancies in SSQP L&F with the integration of STEM education • Discrepancies are problems (Mckillip, 2011). It refers to identifying the reality or issues of the current situation in teaching and learning physics compared to the expectation to the ideal state of teachers' readiness and students' attitude and characteristics towards physics, particularly QP (McKillip, 1987)	QP nature	• Abstract • difficult • concepts contradict classical physics' interpretation
	Insufficiency in QP L&F resources	• QP references are lacking • Learning modules only focus on drilling • Teachers depend on shared materials from social media groups and MOE • The physics textbook is the main references
	Teachers' perception of students' characteristics	• Low expectations of students' performance in physics • exam-oriented mindset • Students are weak with basic concepts of science and mathematics • Passive • Teacher-dependent • Lack of motivation • Different learning style
	Teachers' readiness	• Competency dilemma in teaching QP with integrated STEM education • Physics (QP) is challenging to teach with online class • QP is difficult to understand • Lack of teaching aids • Teachers need to revise QP

FINDINGS AND DISCUSSION

The objective of the need's analysis phase is to identify the need for developing an instructional module for QP at the secondary school level. Hence, the semi-structured interview was carried out to answer the research questions as follows:
To what extent an instructional module is needed in QP L&F?

(a) What are practical instructional strategies and approaches for QP L&F with integrated STEM education based on experts' views?
(b) What are the challenges and expectations of QP L&F with integrated STEM education among teachers?
(c) What are the learners' characteristics and responses towards QP learning based on the literature review and teachers' perceptions?

Two major themes emerged from the thematic analysis: the expectation in QP L&F based on experts and teachers' views and the discrepancies in SSQP-STEM L&F gathered from the teachers' opinions and perspectives. The first theme in Figure 3 denotes teachers' professional development, pedagogical content knowledge, instructional strategy and QP L&F resources. The second theme in Fig. 4, on the other hand, describes the discrepancies of SSQP-STEM L&F in terms of QP nature, QP L&F resources, teachers' perceptions towards students' characteristics in the physics classroom, and the teachers' readiness in teaching QP.

The first theme indicates the expectation towards physics teachers to participate in Professional Learning Community (PLC) and Continuous Profesional Development (CPD) programs, and also recommended engaging actively in self-learning to improve skills in QP L&F. The physics teachers also admitted that they need the training to improve their pedagogical skills and content knowledge in this area even though they took QP courses during first degree. Teachers must have a firm foundation in pedagogical content knowledge, enabling them to integrate their pedagogical knowledge and QP content to ensure that the learning is more attainable to students (Meltzer, 2011). In particular, they need to be well-versed with the contradiction between classical physics (CP) and QP and pose pedagogical skills to cater to 21st-century learners, address the abstractness of the QP concept, and be versatile in applying instructional strategies in the classroom.

The expectation in instructional strategy for QP with integrated STEM education is the recommendation for instructional strategies and teaching aids. Experts recommended active learning strategies such as IBL, activity-based learning (ABL), STEM problem-based learning (STEM PBL), flipped classroom, discrepant event, and clever analogy by engaging students with real-world situations and problem-solving to instil STEM education elements. The experts also emphasised the objective of the lesson must be aligned with the content and evaluation purposes to ensure a meaningful learning experience, which is in line with Taba's (1962) views. For the teaching aids, teachers are recommended to use technology with audio and visuals like YouTube videos and interactive simulation aids, the internet, and create a QP module that caters to teachers' and students' needs.

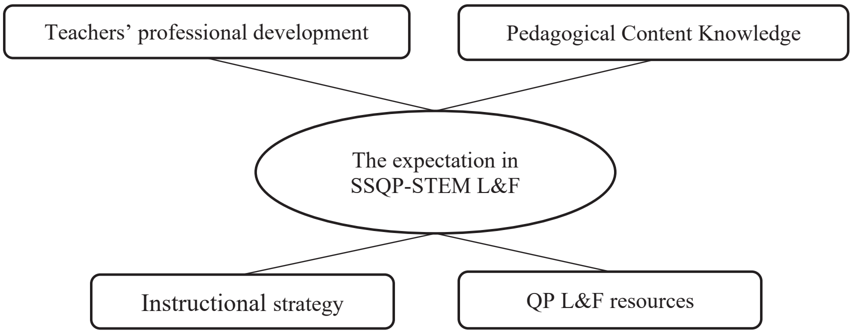

Figure 3 The first theme denotes expectation in QP L&F

The second main theme in Fig. 4 is the identification of the discrepancies or problems which indicate the needs in QP L&F. This theme describes the challenges faced by the teachers in the aspects of QP nature, insufficiency in QP L&F resources, teachers' perceptions towards students' characteristics and their readiness to teach the topic. Both teachers admitted that QP is a difficult topic due to the abstractness and elusiveness of the concepts (Malgieri et al., 2017; Stadermann & Goedhart, 2020). It is also confusing because it contradicts the classical physics views (Bungum et al., 2015).

As this topic is new in the physics curriculum, both teachers feel the resources for QP L&F still lack and hope the education ministry can provide easy access to QP resources. They also relied on the shared materials or teaching aids from social media groups such as Telegram and Facebook for their physics classroom.

In the aspect of teachers' perceptions of characteristics in the physics classroom, the teacher from rural areas perceives that most of his students have low performance with STEM subjects and have a weak foundation in science and mathematics. As a result, the learning progress was slowed down, and some of them were demotivated to study, especially online classes during MCO. However, both teachers agreed that the teacher's attitude influences students' learning motivation, which means they will be more interested to learn when they like the teacher. Many students, particularly in online classes, were passive.

Besides, students were reliant on teachers for academic progress and easily bored in the physics classroom. The teachers were aware that students have different learning styles, and they needed to plan their lessons to cater to students' needs. Meanwhile, in a classroom with an active learning approach, the teachers agreed that it had brought positive outcomes when students were allowed to participate in learning activities. It encouraged active participation, technological use, and improved thinking skills among students.

The teachers' readiness in teaching QP is influenced by their competency level, instructional challenges, and teaching aids availability. Regarding the competency dilemma, the teachers were unsure how QP instruction should be conducted and how it can be taught with STEM integration. The instructional challenges experienced by the teachers were with the online classes due to unstable internet connections, students' low participation, online class preparation, and reporting to the superiors, which caused burnout.

One of the teachers experienced difficulties handling underperforming students who are at risk of being left behind or dropping out during MCO. The teachers have limited time to prepare an effective lesson as they require more time for the SPM examination preparation. Nevertheless, they know an alternative to the 'spoon-feeding' strategy is needed to help students learn better. Apart from that, the teachers are uncertain about the availability of teaching aids for QP because they depend on the textbook and the shared materials from other teachers.

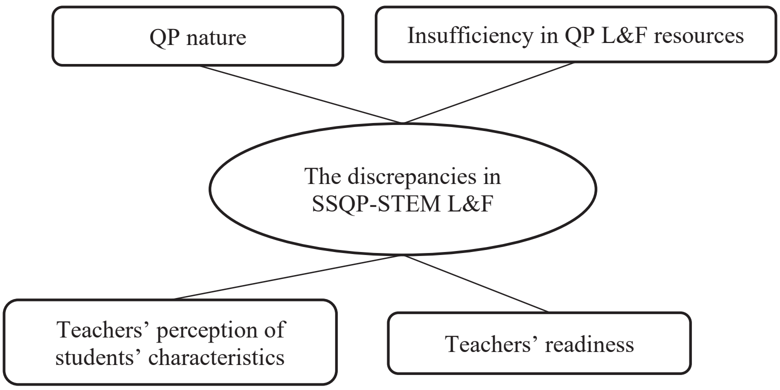

Figure 4 The second theme denotes the discrepancies in SSQP-STEM L&F

IMPLICATION AND CONCLUSION

As an implication and conclusion, the information obtained from this study can facilitate in designing the QP instructional modules that suit the current education situation. The NA study enables the researcher to discover the expectations, problems and identify the needs in QP L&F with integrated STEM education. Although the informants have different school backgrounds, there are similarities in their challenges and needs that can be addressed. This study also discovered valuable recommendations on practical instructional strategies and approaches for QP L&F with integrated STEM education. Hence, the learning materials can be designed based on the needs of the teachers and students that are relevant to the content and learning standard of the physics curriculum. Therefore, this study indicates that the SSQP-STEM Instructional Module should be developed to address the gaps and the needs of teachers and students in QP L&F.

This research is consistent with the TABA model of curriculum development, which emphasises identifying the needs of the learners (Lunenburg, 2011). Hence, the identified discrepancies are gaps that need to be highlighted in designing a flexible and practical instructional module that caters to the current education setting. The needs analysis is also recommended to teachers at school to identify the problems and needs of the students in creating or planning activities or programs to prevent unnecessary expenses or a waste of time (Mckillip, 2011).

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