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Facilitation of Student Questioning in the Malaysian Secondary Science Classroom Using the Investigable Questioning Formulation Technique (IQFT) Protocol

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Received: 3 April 2023 | Revised: 8 May 2023 | Accepted: 15 May 2023

Abstract

This study developed the Investigable Questioning Formulation Technique (IQFT) protocol to formulate investigable questions by following the procedures of design-based

research. As guiding heuristics, the protocol used two provisional design principles based on teaching experience and previous studies that have applied tools for formulating questions, notably, the question formulation technique, SMART goals, and a typology of investigable and non-investigable questions. Two cycles comprising six lesson interventions were completed with two groups ($n = 23$, $n = 25$) of students in the same school in Malaysia. Questions were analyzed using qualitative content analysis and a question typology framework. Findings show the majority of students formulated comparison, exploratory, and validation of mental model questions. Some questions were posed in the prediction, descriptive, and problem-solving categories, but none were categorized as cause and effect, design and make, or pattern seeking. Implications for use of the IQFT protocol to help facilitate Malaysian students' generation of investigable questions, design experiments, and implement open inquiry are discussed.

Keywords

inquiry-based science education – Investigable Questioning Formulation Technique (IQFT) protocol – investigable questions – secondary school science – student questioning

1 Introduction

In inquiry learning, students should ask questions before commencing an investigation. This approach involves a process of exploration, investigation, and experimentation, whereas student questioning refers specifically to the act of asking questions (Carli et al., 2022). While both are important aspects of the learning process, they are not interchangeable, as inquiry learning requires a more structured approach that includes formulating investigable questions, gathering data, analyzing, and interpreting data, and drawing conclusions. In contrast, student questioning can occur at any point in the learning process and can serve as a way for students to clarify their understanding, explore new ideas, or generate hypotheses (Chin & Osborne, 2008).

Ideally, the question to be investigated should be generated by the students since this directly engages them in the inquiry (Chin & Kayalvizhi, 2002; Crawford, 2014). Despite researchers emphasizing the value of students' questions (see Chin & Kayalvizhi, 2002; Crawford, 2014), more than half of the questions that students ask are not investigable questions and do not lend

themselves to a practical investigation (Symington, 1980). Therefore, teachers need to guide students in converting non-investigable questions into investigable questions (Roth & Roychoudhury, 1993). A systematic process for constructing questions is required to assist students in developing questions that are suitable for real-world investigations (Aziza, 2018). Student questioning is the procedure by which students develop, frame, and answer questions to acquire knowledge or resolve mental conflicts (Stokhof et al., 2019). It is an essential tool in inquiry-based science education classrooms as critical questioning is fundamental to the scientific method (Shodell, 1995). Furthermore, contemporary science education objectives see inquiry as part of a fundamental reform that emphasizes the role of questions, evidence, and explanations in science (Brown et al., 2013).

One of the advantages of students' questioning is that it gives students a sense of responsibility and engages them emotionally in science instruction (Singh et al., 2019). It also plays a crucial part in meaningful learning by disclosing the quality of students' thinking and conceptual knowledge, their alternative frameworks and misconceptions, and how they provide their reasoning (Cardoso & Almeida, 2014). Students' questioning is therefore an essential self-regulatory method that increases intrinsic motivation, encourages autonomy and competence, and supports both knowledge acquisition and the growth of meta-cognitive methods (Chin & Osborne, 2008). Although many teachers recognize the significance of students' questioning, its application can be constrained for various reasons. For instance, teachers often favor direct instruction to achieve curriculum objectives and reject students' spontaneous questions to avoid disrupting their carefully scheduled sessions (Rop, 2002).

Stokhof et al. (2019) further highlighted that teachers are concerned that student-generated questions do not necessarily reflect curriculum objectives. In addition, students rarely ask questions, and some questions do not favor information seeking, which means that the number of students who spontaneously raise advanced or open-ended questions about inquiry activities tends to be limited (Cardoso & Almeida, 2014). Thus, students need to be immersed in explicit teaching questioning strategies, since teaching students to ask and respond to questions is crucial if they are to learn to communicate and reason together effectively (Gillies et al., 2014). This point was supported by Nichols et al.'s (2017) study, which highlighted that when students learned about questioning strategies, they developed questioning and science inquiry behaviors that may enhance their involvement in science and society in the future. Teachers may also be enabled to foster the skills required by the curriculum in their students.

To ensure that students' questions are essential to the inquiry activities they will be performing, they need to develop investigable questions. In essence, if students do not begin the inquiry with an appropriate investigable question, they will encounter difficulties throughout the remainder of their investigation unless they adjust their questions and recommence their investigation (Erumit et al., 2019). Crafting questions that can be empirically investigated is vital for establishing connections between data and knowledge claims, forming scientific arguments, and comprehending the role of debate in developing scientific knowledge (O'Neill & Polman, 2004). Because investigable questions are crucial to scientific inquiry, teachers must help their students acquire the ability to formulate them. Sharkaway (2010) proposed four principles to help students generate investigable questions: (a) justify the importance of their questions, (b) give students opportunities to investigate real phenomena, (c) demonstrate how to ask probing inquiries and provide an example of question beginnings, and (d) provide training in questioning techniques and improve the investigation questions.

A number of issues arise when encouraging students to construct investigable questions in an inquiry-based science education lesson. Creating an investigable question requires a significant amount of effort and skill on the part of the teacher, as students must retain ownership of the questions as they are modified (Nesbit et al., 2004). As the process of inquiry takes time, teachers may be concerned about adhering to a strict schedule, and they may prefer to sacrifice the time necessary to explore investigable questions (Buczynski & Hansen, 2010). Moreover, ample stimuli must be provided to students from the reading materials, any arising discrepancies, and unexpected events to offer the impetus for discussion and access to the knowledge required to generate investigable and researchable questions (Webb, 2010). Chin and Kayalvizhi (2002) offered strategies for encouraging students to ask investigable questions that included explaining in detail to students the nature of investigations, the terms and concepts related to investigations, the many kinds of investigations that can be conducted, and, in particular, the characteristics of good investigable questions. Students should also know how to differentiate between investigable and non-investigable questions. Therefore, this study aimed to develop the Investigable Question Formulation Technique (IQFT) protocol based on previous research concerning the application of the question formulation method (Rothstein & Santana, 2017), SMART goals (Brown et al., 2016) and the typology of investigable and non-investigable questions (Chin, 2002).

This study seeks to make a valuable contribution to the field of science education in Malaysia and the broader Southeast Asian region, with a particular

focus on training students to ask scientific questions. The Malaysia Education Blueprint 2013–2025 highlighted the government's strategies to enhance the quality of education in Malaysia, namely, to equip the nation to address 21st-century challenges and achieve greater success (MOE, 2013). This aligns with 21st-century learning principles that emphasize the development of students' higher-order thinking skills. Hassan et al. (2021) suggested that student questioning activities can promote the development of higher-order thinking skills. However, there has been little research on student questioning, particularly investigable questions, within the Malaysian context. Therefore, the IQFT protocol developed serves as a scaffolding tool that teachers can use to support and guide students to improve their questioning skills. It has been found that encouraging student questioning can have a positive impact on student motivation, engagement, and learning outcomes in science and promote the development of scientific inquiry skills such as hypothesis testing and experimental design (Chin & Osborne, 2008).

With these points in mind, the study aims to address the following research question:

1. In what ways can the IQFT protocol facilitate students to formulate investigable questions?

2 Problem Statement

2.1 Questioning Activities

Teacher and student questions play an important role in determining the inquiry process. When teachers indirectly diversify questioning approaches, using approaches such as closed- and open-ended questions, they form an interaction that can improve students' cognitive development (Chen et al., 2017). In addition, open-ended questions stimulate students' engagement in group discussions (Kademian & Davis, 2018). Likewise, student questions are significant in inquiry-based science education and science learning (Herranen & Aksela, 2019). However, teachers face the problem of making student questions useful for curriculum learning (Stokhof et al., 2020), and although students learn in informal contexts outside of the classroom, they may still find it difficult to ask questions (Singh et al., 2019). In addition, some family cultures discourage children from asking questions, as the child is expected to obey the parents' instructions (Singh et al., 2019).

In spite of these problems, there are a number of tools that teachers can harness. According to Stokhof et al. (2020), in order to foster and support a

classroom environment where student questioning can take place, four design principles need to be harnessed: (a) describe the curriculum objectives; (b) support question development; (c) establish shared responsibility; and (d) visualize the construction of collective knowledge. To effectively engage students and align their learning with curriculum objectives, teachers must first identify the key concepts in the topic being studied. This serves as a conceptual foundation that balances students' intellectual curiosity and fosters structured exploration of their personal questions. The teacher should then facilitate an environment where all student questions are encouraged and celebrated, and these questions are discussed as a group in class. Utilizing a collective visual platform can also be highly beneficial, as it provides a visual representation of students' prior knowledge and serves as a starting point for collaborative knowledge building. This approach also enables teachers to effectively monitor and evaluate student learning progress.

2.2 *Facilitating Students' Questions for Inquiry*

Student questions can be generated orally or through writing (Singh et al., 2019). Questioning is one of the key practical skills utilized in science laboratories (Hinampas et al., 2018). Effective questioning methods can encourage students to think more critically (Hinampas et al., 2018). There are many tools or strategies that can be employed to make student questioning more effective, notably the use of mind maps (Stokhof et al., 2020) and jigsaws (Blonder et al., 2015). According to Stokhof et al. (2020), knowledge visualized in the form of mind maps supports students' understanding of the concepts learned. In addition, students are encouraged to ask questions related to their real-life problems (Blonder et al., 2015). In open inquiry, students create research questions, organize the inquiry, and carry out the investigation (Herranen & Aksela, 2019). This process of inquiry requires students' motivation to learn about science and science self-efficacy (Areepattamannil et al., 2020). Therefore, students in Malaysia need to be guided to formulate investigable questions because in traditional Malaysian classrooms, questioning is not widely utilized, and the majority of teacher questions tend to be of a low quality (Mat Noor, 2021). Thus, students tend to lack opportunities to apply their critical thinking skills (Yin Peen & Yusof Arshad, 2014).

Despite the importance of student questioning in science education, students may struggle to generate effective questions, and teachers need more effective strategies to guide students in formulating investigable questions that promote critical thinking, science self-efficacy, and motivation to learn. Different tools and strategies such as mind maps and jigsaws have been

proposed, but their effectiveness in improving student questioning needs to be further explored.

3 Research Background

Previous studies have conceptualized several questioning protocols for various purposes, including promoting conceptual understanding, developing science process skills, and facilitating exam preparation (see Aflalo, 2021; Blonder et al., 2015; Tseng et al., 2015; Zydney & Grincewicz, 2011). While these protocols have been limited, promoting the creation of investigable questions can shift students' focus towards the learning process and promote active learning, despite requiring more effort. Aflalo (2021) suggested making the development of student questions a more prominent part of the curriculum. Herranen and Aksela's (2019) review also underscored the importance of questioning in teacher education, as it is a practical and critical form of inquiry.

Investigable questions give students the opportunity to create, gather, analyze, and interpret data and draw conclusions. Three previous studies have developed protocols for formulating questions, including investigable questions, as shown in Table 1. Chin (2002) provided five recommendations to aid students in creating an appropriate problem or research question. First, teachers need to clarify the different types of investigable and non-investigable questions. Second, teachers need to explain the terms and concepts that apply to investigations to the students. Third, through questioning and discussion, they should assist students to convert their non-investigable questions into investigable questions. Fourth, they should encourage students to utilize their prior knowledge and interests. Thus, teachers act as facilitators, enabling students to make connections between what they already know and what they want to learn. Last, teachers should create an environment that supports students to ask questions and pose problems.

Tseng et al. (2015) introduced the "big idea, divergent thinking and convergent thinking" model to scaffold students' inquiry learning. In this model, three stages were identified for teachers and students. In Stage 1, teachers identify big ideas while students identify what is known. Next, in Stage 2, teachers use divergent thinking while students use the mandala thinking strategy, which aids in developing critical thinking skills and fostering self-awareness. The strategy involves creating a diagram with the central concept in the center of the circle and related ideas, concepts, and information radiating outwards. Last, in Stage 3, teachers use convergent thinking while students make

TABLE 1 Some protocols for formulating investigable or scientific questions

Authors	Chin (2002)	Tseng et al. (2015)	Singh et al. (2019)
Protocols / suggestions	i) Explain the different types of investigable and non-investigable questions to students. ii) Teach students the terms and concepts used in investigations. iii) Through questioning and discussion, assist students in converting their non-investigable questions into investigable questions. iv) Utilize students' prior knowledge and interests. Encourage them to make connections between what they already know and what they want to learn. v) Create an environment that supports asking questions and posing problems.	Big idea, divergent thinking, and convergent thinking model Plan for teachers <i>Stage 1:</i> Identify big ideas. <i>Stage 2:</i> Use divergent thinking. <i>Stage 3:</i> Use convergent thinking. Plan for students <i>Stage 1:</i> Identify what is known. <i>Stage 2:</i> Use the mandala thinking strategy. <i>Stage 3:</i> Make a plan.	<i>Stage 1:</i> Indirect <i>Stage 2:</i> Less indirect <i>Stage 3:</i> Somewhat direct <i>Stage 4:</i> Most direct
Objectives	To generate investigable problems and questions	To scaffold students' inquiry learning	To encourage students to ask questions

a plan. This model is beneficial because teachers' and students' roles are clearly delineated. This model also encourages students to identify variables in experiments.

Singh et al. (2019) investigated the reasoning students use to formulate questions. Their study proposed four stages to encourage students to ask questions. Stage 1 is indirect, which means that teachers call students to choose a question focus such as a tree, indicating this by saying only "come here." Stage 2 is less indirect, which means that teachers start looking at the tree so that the students get interested in it. Stage 3 is somewhat direct, as teachers start asking

students to look at the tree, with ambiguous exclamations such as, “Oh! Look!” Last, Stage 4 is the most direct stage, in which teachers ask students to ask questions about the tree. The purpose of this step-by-step process is to encourage students to engage with the lesson.

The suggestions of previous studies offer valuable guidelines for teachers, particularly regarding student engagement. However, problems arise for those teachers who do not have sufficient knowledge and experience to guide students to formulate open investigations. In addition, these suggestions offer neither examples of investigable questions nor clues as to how to formulate them. Students need to be given some examples of investigable questions to facilitate their generation of these kinds of questions. Otherwise, students may continue to generate the same types of questions, such as cause and effect or exploratory questions, which are limited in their scope. Therefore, there is a need for a more structured protocol and rubric to offer further guidelines for teachers.

4 Methodology

The study followed the principles of design-based research (DBR; Baumgartner et al., 2003) to generate knowledge that teachers can use to instruct students in the development of investigable questions. DBR utilizes practitioner-oriented methodologies because the objective is to bring about real change and enhance learning outcomes while ensuring fairness and inclusivity for all students (Hall, 2020). In addition, as a methodology, DBR utilizes design as a foundation to develop learning innovations through the research process of theory creation and innovation design (Kaanklao & Suwathanpornkul, 2018). The three key aspects of theory building in DBR are intervene, innovate, and iterate (Hall, 2020). DBR allows for the development and refinement of interventions in real-world contexts. This approach emphasizes collaboration between researchers and practitioners and provides opportunities for iterative cycles of design, implementation, and evaluation. In addition, DBR emphasizes the importance of studying complex, dynamic educational environments, such as science classrooms, and provides a framework for addressing practical problems in these settings. Therefore, the research team made changes in practice to improve student inquiry learning practices.

4.1 *Participants and Research Context*

In cycle one of the study, the IQFT protocol was implemented with two groups (25 students in Group A and 23 students in Group B) from an Islamic school

in Malaysia. Group A was comprised of all male students while group B was comprised of all female students. While this study did not specifically examine gender differences, due to the unique circumstance of gender-segregated classes in this particular school, the educators made the decision to implement the protocol using the same single-sex grouping that students experienced in their regular classroom. The IQFT protocol was then repeated for two cycles using different questions focused on the menstrual cycle, states of matter, the human digestive system, acids and bases, water quality, and heat. The selected science topics were aligned with the curriculum requirements of the Malaysian Secondary Science Curriculum Standards (MOE, 2016).

At the time of the study, the first author was employed as a science teacher in a suburban area. As a qualified teacher, she was interested in using research to improve her classroom practice. To this end, she took on the dual role of teacher-researcher, conducting research while also teaching her students. This approach involved using her expertise to investigate her own practice and identify ways to improve it. However, it is important to note that self-reflection and evaluation can be biased, as Herr and Anderson (2015) pointed out. To minimize potential biases, the research team enlisted the help of three external experts to evaluate the quality of the student questions. This evaluation ensured that the questions were suitable and aligned with Chin and Kayalvizhi's (2002) interpretations.

TABLE 2 A summary of the two cycles of intervention

Group	Cycle 1				Cycle 2							
	A	B	A	B	A	B	A	B	A	B	A	B
Topic	Menstrual cycle		States of matter		Human digestive system		Acids and bases		Water quality		Heat	
Question focus	print image of the menstrual cycle		A beaker with ice cubes		print image of the human digestive system		print image of fruits		Video on water pollution		Video on green technology and the greenhouse effect	
Lesson time	60 minutes		60 minutes		60 minutes		60 minutes		60 minutes		60 minutes	

Table 2 provides a summary of the intervention. The students were 13 years old when they learned about the menstrual cycle and states of matter. The same participating students were 14 years old when Cycle 2 on the topics of the human digestive system, acids and bases, water quality, and heat took place. This was because the teacher had completed teaching for that year, so the topics were carried over. The students were in small groups consisting of four to six students.

4.2 *Designing the IQFT Protocol*

Two tentative design principles served as the guiding heuristics for the protocol developed as part of this research: earlier teaching experience and earlier studies that applied a question formulation technique (Rothstein & Santana, 2017). The IQFT protocol was initially developed by combining the research framework from the question formulation technique (Rothstein & Santana, 2017), SMART goals (Brown et al., 2016), and typology of investigable and non-investigable questions (Chin, 2002). It is fundamental that pupils who are motivated by curiosity acquire and retain information more effectively and take more responsibility for their learning. Students should focus their questions on visual, auditory, or technological learning aids since these enhance their science learning (Kamarudin et al., 2022). The IQFT protocol developed for this study consists of eight main steps, which are listed in Table 3 below.

TABLE 3 Investigable Questioning Formulation Technique (IQFT) protocol used to formulate questions

Steps	Description
Step 1: Choose the question focus	The teacher will choose a suitable question focus as a stimulus for students to formulate questions. This can be achieved by utilizing a variety of teaching tools in any format that can get students to think critically.
Step 2: Introduce the rules before the questioning technique	The rules are (i) ask as many questions as possible, (ii) continuously discuss the questions, (iii) list all the questions discussed, and (iv) convert any statement into a question.

TABLE 3 Investigable Questioning Formulation Technique (IQFT) protocol (*cont.*)

Steps	Description
Step 3: Generate questions individually	Every member of the group must generate at least one question.
Step 4: List all questions	A group leader will write down all the questions produced by the members.
Step 5: Introduce the rubric	Students identify the characteristics of investigable questions by introducing the SMART rubric, which stands for specific, measurable, achievable, relevant, and timely.
Step 6: Grade investigable questions	Students will use the SMART rubric to discuss and evaluate all the generated questions.
Step 7: Arrange all the investigable questions	Students will arrange and share the investigable questions with other groups based on the SMART characteristics (i.e., they will be arranged by their scores on the rubric).
Step 8: Reflect on and design the investigation	The teacher will discuss the most important characteristics of investigable questions with students and facilitate their design of scientific investigations to answer the questions.

4.3 *Implementing the IQFT Protocol in Two Cycles*

This study was conducted in a Malaysian secondary school science education context, where the science curriculum was aimed at cultivating students' science literacy, critical thinking skills, and ability to apply scientific knowledge in solving real-life problems (Mat Noor, 2021; MOE, 2016). The Standard Science Curriculum covered three key areas: knowledge, skills, and values. Students were expected to explore these areas through an inquiry-based approach that promotes the development of a scientific mindset. This approach focused on student-centered learning, constructivism, contextual learning, problem-based learning, mastery learning and other relevant strategies and methods. Through these methods, students were encouraged to take an active role in their learning, apply scientific principles to real-world situations, and

develop critical thinking skills that will serve them well in their future studies and careers (MOE, 2016).

4.3.1 Question Formulation Technique Application: Cycle 1

During Cycle 1, students were taught to generate questions using the question formulation technique (Rothstein & Santana, 2017). The question formulation technique consists of six components: (i) focus the question, (ii) construct the question, (iii) give examples of open- and closed-ended type questions, (iv) prioritize the question, (v) plan the next activity, and (vi) reflect. Students were introduced to the first topic, which focused on the menstrual cycle, which is part of the science curriculum mandated by the Ministry of Education for this age group. The students then combined the generated questions in groups and discussed how each question had been identified and whether it was a closed- or an open-ended question. Students were taught to identify the different types of question words, notably that “what,” “where,” and “when” questions are closed-ended questions, while “how” and “why” questions are open-ended questions. Students then arranged the questions according to the priority they wanted to address. Finally, students chose three main questions from their respective groups to discuss in class and suggested activities based on those questions.

4.3.2 IQFT Protocol Application: Cycle 2

Cycle 2 involved five topics: states of matter, the human digestive system, acids and bases, water quality, and heat. During this phase, the IQFT protocol was first introduced to students. Following this, an exploration of the questions generated by the students was conducted based on the five topics. Students underwent all eight steps in the IQFT protocol. In Step 8, when reflecting and planning the next action, students simply discussed the selected question with the teacher and suggested activities based on that question.

4.4 *Reflections Between the Cycles*

4.4.1 Question Formulation Technique Reflection: Cycle 1

In the beginning, the students were introduced to the questioning protocol. The teacher introduced question words that distinguished between closed- and open-ended questions to encourage students to generate closed- and open-ended questions. Instead of displaying digital images shown at the front of the classroom, printed images were given to students in each group. However, these images did not appear to interest the students and during observations of students working in groups, they appeared to look bored. Therefore, students did not carry out activities based on the constructed questions during

the menstrual cycle topic. Based on the teachers' observations, students could produce questions, but the questions did not direct them towards an investigation. In addition, looking more closely at the context of the questions generated, questions that began with the question word "what" also directed students towards an investigation. Thus, the teacher concluded that the existing protocol needed to be improved so that the students could produce questions of an investigative nature.

4.4.2 IQFT Reflections: Cycle 2

Students had already gained experience after going through Cycle 1. Therefore, they found it easier to produce questions using the IQFT protocol in the second cycle. However, students only succeeded in generating a few investigable questions. Also, during this cycle, the teacher still used a printed image even though in Cycle 1 the students looked bored. This was because pictures of the human digestive system and fruits were immediately recognizable to teachers and students who already had prior knowledge of these topics from primary school. Thus, the main focus of Cycle 2 was to look at the types of questions generated by students after introducing the IQFT Protocol. Students' ability to generate questions was also influenced by their prior knowledge from primary school. Thus, students' basic primary school knowledge helped them to generate questions.

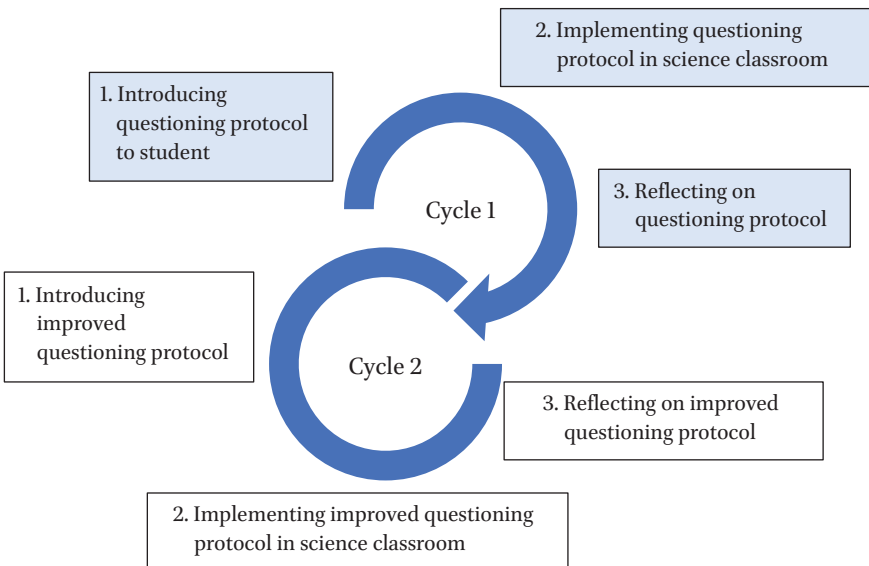


FIGURE 1 The research framework for cycles 1 and 2

The questions posed by the students were evaluated to determine whether they were suitable for investigation based on their content and practicality. The questions were sent to three external experts for quality evaluation to ensure that they corresponded with Chin and Kayalvizhi's (2002) four factors: closed- or open-ended questions, procedural questions, conceptual questions, and the questions' relevance to the students' investigation. Coding categories were developed for the questions that were derived from existing literature on questions that students had asked (see Chin & Kayalvizhi, 2002). The present study focused on the types of questions formulated and their potential for conducting investigations. Figure 1 shows the research framework both cycles.

5 Findings

Students produced various types of questions after the question focus had been established. The questions generated consisted of investigable and non-investigable questions. However, a handful of students had difficulty in constructing questions, and in the end they did not ask questions. Students who faced problems were helped by being offered clues. The teacher gave instructions in the form of an incomplete sentence arrangement. Students needed to identify the appropriate type of sentence structure and fill in the blanks with variables they felt were relevant. Finally, after being given clues, students successfully generated questions. However, students were still not producing many investigable questions. Through skilled teacher questioning and discussion, students were assisted in converting their non-investigable questions into investigable ones (Chin & Kayalvizhi, 2002).

The following is the order of sentences given to students who had difficulty in constructing questions:

1. Which is the most ____?
2. How does ____ affect ____?
3. What will happen if ____?
4. What is the effect of ____ on ____?
5. What are the factors that affect ____?
6. What needs to be changed in ____ for ____ to be more efficient?
7. What changes occur during ____?
8. What is the relationship between ____ and ____?
9. How can I identify and differentiate between ____ and ____?
10. How can ____ be made into a model in concrete material?

For analysis, the questions generated by the students were classified into two groups: investigable and non-investigable.

5.1 *Investigable Questions*

Investigable questions allow students to carry out experiments or projects. Students generate and collect data during the investigation, analyze and interpret the data, and draw conclusions to answer research questions. Suppose a student-generated question only requires one to ask someone a question or find a book or other secondary source without manipulating concrete materials, apparatus, or instruments. In that case, the question is considered non-investigable (Chin & Kayalvizhi, 2002). The typology of questions for open investigations in this study was taken from that proposed by Chin and Kayalvizhi, who asserted that there are nine types of investigable questions: (i) comparison, (ii) cause and effect, (iii) prediction, (iv) design and make, (v) exploratory, (vi) descriptive, (vii) pattern seeking, (viii) problem-solving, and (ix) validation of mental model questions.

When students can formulate investigable questions, they are empowered to collect and analyze original data, draw conclusions based on first-hand evidence, and effectively answer the investigable question at hand. Chin and Kayalvizhi (2002) offered some interpretations on types of investigable questions. Comparison questions require the selection of one option from multiple items that are being evaluated. Cause and effect questions are inquiries that explore the causal mechanisms and relationships between events or phenomena. Prediction questions require some degree of speculation and may involve testing a mini-theory or validating a hypothesis. Design-and-make questions pertain to the creation of something for a practical purpose and are typically linked with the resolution of technological challenges. Exploratory questions are used for the initial investigation of a topic, before the focus is narrowed down, and may involve some trial and error. Descriptive questions prompt students to closely observe an object or event and provide a detailed description of it. Pattern seeking questions are particularly well-suited for surveys that explore natural biological phenomena, such as ecological systems, weather patterns, or genetics, where manipulating or controlling factors may be difficult for students. Problem-solving questions that begin with “Can you find a way to ...” encourage students to apply their knowledge in innovative and creative ways to resolve a problem. Finally, The validation of mental model category involves testing and refining mental or conceptual models against evidence and is prompted by students’ desire to understand and explain puzzling phenomena, often involving hands-on investigation.

TABLE 4 Examples of students' questions

Topic	Question	Investigable ^a									Non-investigable ^b		
		i	ii	iii	iv	v	vi	vii	viii	ix	i	ii	iii
Menstrual cycle	What affects the menstrual cycle?										/		
	How can a menstrual cycle model be constructed?										/		
States of matter	In what ways can a woman's emotions interfere with the menstrual cycle?												/
	Why does the menstrual cycle occur?												/
	What factors cause ice to melt quickly (in less than 5 minutes)?					/							
	What conditions will make ice melt quickly?	/											
	What quantity of ice is needed to melt into 25 ml of water?												/
	Which of these solvents will cause the ice to float?	/											
	What changes take place during the water cycle?									/			
	Why does heat cause ice to melt?												/

a Investigable questions: (i) Comparison, (ii) cause and effect, (iii) prediction, (iv) design and make, (v) exploratory, (vi) descriptive, (vii) pattern seeking, (viii) problem-solving, and (ix) validation of mental model.

b Non-investigable questions: (i) Basic information, (ii) complex information, and (iii) philosophical or religious questions.

TABLE 4 Examples of students' questions (*cont.*)

Topic	Question	Investigable									Non-investigable			
		i	ii	iii	iv	v	vi	vii	viii	ix	i	ii	iii	
Human digestive system	How can a model of the digestive system be constructed?								/					
	How can the digestive system be modeled?								/					
	What is the function of the esophagus?											/		
	What is the meaning of food digestion?												/	
Acids and bases	Which of these substances will change the color of blue litmus paper?	/												
	Which type of soil pH is the most suitable for plant growth?	/												
	How can we identify and distinguish the properties of three unknown clear solutions?								/					
	Why do acids and alkalis corrode?												/	
Water quality	Why is acidic waste from factories treated with alkali before being released?									/				
	What are the factors that cause contamination in three water samples?													/
	What will happen if this water pollution continues?			/										
	What steps can be taken to prevent water pollution?									/				
	How can one clean three water samples?												/	

TABLE 4 Examples of students' questions (*cont.*)

Topic	Question	Investigable									Non-investigable			
		i	ii	iii	iv	v	vi	vii	viii	ix	i	ii	iii	
Heat	What are some examples of polluted rivers in Malaysia?										/			
	What will happen to fish in the polluted rivers?											/		
	How can a green building model be constructed?												/	
	What characteristics of a home keep it from becoming too hot, even without air conditioning?					/								
	How can a model of global warming be constructed?												/	
Total	What is the most effective method for lowering electricity costs?													/
	How can climate change be modeled?													/
	What is the best way to reduce plastic waste?													/
	Why can a solar energy save electricity?													/
	How does light affect trees?	6	-	1	-	5	1	1	-	1	6	7	6	-

Note: The questions were posed by students individually while working in their groups. Students' original wording has been preserved. The / mark appearing in the columns indicates a category of questions generated by students.

5.2 *Non-Investigable Questions*

Non-investigable questions include: (i) basic information, (ii) complex information, and (iii) philosophical or religious questions. Basic information questions are questions that ask for uncomplicated facts or information that are readily accessible through sources such as books, the internet, or asking someone. Complex information questions are challenging to answer and typically require detailed explanations or in-depth knowledge that may be beyond a student's grasp. Philosophical or religious questions may not have a scientifically verifiable answer or may be beyond the scope of science.

Students generated a total of 200 questions, both individually and in groups. Table 4 illustrates some of the students' questions related to the six topics explored in this study. The topics involved were the menstrual cycle, states of matter, the human digestive system, acids and bases, water quality, and heat. Students already had prior knowledge because all topics except water quality had been taught in primary school. The questions collected were the result of student discussions during the group sessions. According to Muhamad Dah and Mat Noor (2021), group discussions improve the quality of student questioning. The teacher issued the questions with the highest scores based on the SMART rubric. However, on the topic of heat, students produced questions individually because the teacher-researcher wanted to evaluate students' ability to create investigable questions after several training sessions in using the protocol. The heat topic led to the formulation of the most investigable questions, totaling six questions. The students were able to generate 22 (11%) investigable questions out of the 200 total questions that were formulated by both groups of students. The topics involved were chemistry, heat, plants, energy, force, and light, as shown in Table 5.

TABLE 5 List of topics related to the students' questions

Topic	Number of questions	Number of investigable questions
Menstrual cycle	12	2
States of matter	19	5
Human digestive system	32	2
Acids and bases	30	3
Water quality	28	4
Heat	79	6
Total	200	22
% investigable	—	11.0

6 Discussions

The findings of the present research reinforce those of Chin and Kayalvizhi's (2002) study, in which the total percentage of investigable questions generated by students was 11.7%. However, after the students were shown the examples of investigable questions, the percentage increased to 71.4% (Chin & Kayalvizhi, 2002). The topics investigated in Chin and Kayalvizhi's (2002) study included energy, chemistry, human biology, the solar system and the universe, evolution, plants, religion, weather, animals, communications technology, light, aerodynamics, and electricity. Selection of the topic therefore affects the quality of students' questioning (Muhamad Dah & Mat Noor, 2021).

6.1 *The Types of Investigable Questions*

In this study, students generated six types of investigable questions: comparison, prediction, exploratory, descriptive, problem-solving and validation of mental model questions. None of the questions formulated by the students fell into cause and effect, design and make and pattern seeking categories.

6.1.1 Comparison Category

Comparison questions require students to choose between several objects to be tested. According to Chin and Kayalvizhi (2002), there are two types of comparison questions: make a choice and classification. In a make-a-choice question, students compare and choose from a set of things based on a specific characteristic. Such questions challenge students to compare a number of entities and to select one based on a particular attribute (Chin & Kayalvizhi, 2002). Examples of questions students generated in the comparison category from the present study were: "Which condition will make ice melt quickly?" "Which of these substances will change the color of blue litmus paper?" and "Which type of soil pH is the most suitable for plant growth?" The questions "What is the most effective method for lowering electricity costs?" and "What is the best way to reduce plastic waste?" were also comparison questions that could help students to run a project to identify methods to reduce electricity bills. Students determined that they could record the reading of the electricity bill each month and thus monitor electricity consumption. Similar to Kauble's (2011) study, students discussed what would be the best way to clean up an oil spill. Kauble's suggested strategy was to measure the amount of oil removed and evaluate the cleanliness of the seashore after students had decided how they would proceed in teams.

When engaging with comparison questions, students must compare the features of many substances and categorize them into groups based on observable or tested characteristics. An example of a classification question is: "Which of

these solutions will make ice float in it?" There are two possibilities: ice will either float or sink when put into solutions of different densities. Comparison questions are very familiar to students because students make choices and decisions related to such questions in their daily lives. To answer this type of question, students need to experiment with the factors that cause the phenomenon or situation. For example, the mass of ice cubes was measured as a controlled variable. The location of ice was placed as a manipulated variable and the time needed for it to melt was a response variable. Students planned and conducted experiments, analyzed the results, and drew conclusions.

This approach was similar to that adopted in Vowell and Phillips' (2015) study, in which students explored the three states of matter (solids, liquids, and gases) by monitoring changes and taking part in selected activities using balloons and chocolate as part of the teacher's specially designed hands-on science class. According to Singh et al. (2019), investigable questions were often verified by evidence that the students actually did investigate: they collected data in an effort to find answers. However, Prins (2020) categorized questions that contain opinion words (e.g., "best" and "better") as non-investigable questions. This contradicts our criteria for investigable questions. According to Prins (2020), an example of a non-investigable question is: "What type of soil is best for plant growth?" This reflects how the term "investigable question" is open to different interpretations on the part of researchers or teachers.

6.1.2 Cause and Effect Category

No question fell into the cause and effect category. This category refers to the relationship between two variables that affect another variable (Chin, 2002). One such example is a question such as: "How does the temperature of the solvent affect the rate of solubility?" Students generate inferences on how the solute's size affects the rate of solubility. To answer this question, students experiment and manipulate one variable to gauge its effect on the other variable. Students also control for certain variables while conducting experiments. In this study, student questions such as "What factors cause ice to melt quickly (in less than 5 minutes)?" looked like cause and effect questions. However, only one variable was mentioned in this question.

In West et al.'s (2015) study, students deconstructed already engineered objects (e.g., various coffeemakers) using engineering concepts to offer scientific reasons (e.g., factors affecting solubility) for the design elements, which was similar to our prediction. The teacher had trained the students to construct a hypothesis sentence, in other words, "if ___ then ___," while planning

the experiment. In the current study, however, although students were given clues, no questions were generated in the cause and effect category. Students may have been confused or encountered complications in identifying the variables involved when constructing a question, even when given the focus of the question. Students were already familiar with the questions or problems presented by the teacher before the experiment. Once the teacher had given the investigation question, the student only needed to construct a hypothesis based on the question and identify the variables. Thus, students felt comfortable while planning and conducting experiments and drawing conclusions. However, it must be noted that this “spoon-feeding” method is not the most stimulating one for students undertaking scientific inquiry. Therefore, teachers should encourage their students to learn by asking questions that draw on their existing knowledge (Gerhátová et al., 2021).

6.1.3 Prediction Category

Only one question generated by students fell into the prediction category: “What will happen if this water pollution continues?” Prediction category questions involve speculations made to test a theory (Chin & Kayalvizhi, 2002). Usually, the outline of the prediction question is something like: “What will happen if ___?” Questions such as this could lead students to experience a sense of wonder and encourage them to potentially run a project to find answers. For example, students could choose to observe aquatic life and record the pH of river water or conduct interviews or surveys with residents about their perceptions of the polluted river to then run awareness campaign on water pollution where they could share the data they collected and analyzed. They may then be motivated to introduce residents to ways to reduce water pollution. This example demonstrate how an investigable question, which cannot be easily resolved by reading a book or an article on the internet (Prins, 2020), can be more productive for students’ active learning.

Collaboration between teachers, students and the local community can be achieved, especially when sharing experiences, knowledge, and details about finances. This collaboration acts as a scaffolding to support the teacher in the inquiry process (Adler et al., 2019). Eventually, students become aware of the importance of caring for the environment and being responsible for and concerned about environmental change. Therefore, indirectly, such projects can produce creative, critical, and innovative students. Students are responsible for formulating and constructing new ways of thinking, while teachers need to foster students’ creative activity (van Zee et al., 2001).

6.1.4 Design and Make Category

Students did not construct any questions in the design-and-make category. Questions in this category direct students towards the construction of a tool (Chin & Kayalvizhi, 2002). The primary purpose is to manipulate the variables to produce a device according to the desired requirements. According to Prins (2020), one criterion for investigable questions is that they can be answered with the materials and time available. Therefore, questions in this category are investigable because students need to set up an experiment or project to answer the question.

On the topic of heat, students came up with questions such as “How can one build a thermos to minimize heat loss?” This question is similar to those mentioned in Schnittka et al.’s (2010) study, in which students designed and made penguin homes. Through their project work, students learned about thermal energy transfer by radiation, convection, and conduction. Next, students tested materials, exploring their ability to slow thermal energy transfer to keep the ice penguins cool. After testing the materials, students built their penguin homes, and then saw how well the dwellings kept the penguin-shaped ice cubes from melting in a test oven.

6.1.5 Exploratory Category

Five student-generated questions fell into the exploratory category. The questions were: “What factors cause ice to melt quickly (in less than 5 minutes)?” “What are the factors that cause contamination in three water samples?” “What steps can be taken to prevent water pollution?” “How can one clean three water samples?” and “What characteristics of the home keep it from becoming too hot, even without air conditioning?” Exploratory category questions involve cause-and-effect relationships (Chin & Kayalvizhi, 2002). However, the exploratory category does not define the variables involved. Students need to engage in explorations to answer the investigation questions. For example, a question such as “What characteristics of the home keep it from becoming too hot, even without air conditioning?” involved students needing to find information about house characteristics that ensured they do not become hot.

Some approaches they adopted were to analyze search engines and examine the design of homes in their residential area. Students also carried out surveys of residents in their villages and housing estates. In addition, they conducted interviews with architects. Students also related the theory of reflection and heat absorption to house design. Finally, students presented the findings through sketches of house designs. Mahaya et al. (2015) proposed an activity where students explore water sanitation and testing methods, including solar pasteurization and the Colilert test for total coliform bacteria and *Escherichia*

coli. These investigations are relevant to inquiry-based water quality labs for high school biology, chemistry, and environmental science. However, according to Prins (2020), the question requires variables that can be observed or measured and then categorized as investigable questions, which contradicts our criteria.

6.1.6 Descriptive Category

Students generated one question in the descriptive category. Descriptive category questions require students to make careful, in-depth, and systematic observations (Chin & Kayalvizhi, 2002). The observation activities suggested in Chin and Kayalvizhi's study seed germination, tree growth, and the life cycle of insects such as butterflies. Carrying out the observations necessary to answer this type of question provides a variety of information to students. Making observations is one of the key skills of the science process. Students use the senses of sight, hearing, touch, taste or smell to gather information about an object or phenomenon. In addition, the science process skills involved utilize spatial and temporal relationships. Students describe the change of parameters with time. Examples of parameters include shape, size, volume, weight, and mass.

The descriptive question students generated was "What changes take place during the water cycle?" Students made and recorded observations in their science journals. Since condensation, evaporation, and transpiration are involved in the water cycle, students observed the physical changes that take place. This activity paralleled the one identified in Klosterman et al.'s (2014) study, which proposed an activity to engage students in conversations about plants, their characteristics, functions, and genetic diversity, as manifested in the variety of tomato shapes and sizes found in a grocery store. Singh et al. (2019) further studied a student question: "What possible colors can leaves be?" In their study, students searched for and identified various colors in order to answer the question, and then tested the thickness of leaves by feeling them in order to find out whether some leaves were thinner than others.

6.1.7 Pattern Seeking Category

No question was generated in the pattern seeking category. This category of question involves a survey of natural biological phenomena (Chin & Kayalvizhi, 2002). Examples of phenomena are ecological systems, weather, and genetic variation. Students are unable to control for any of the variables. An example of a question for this category is: "What are the communities and types of interactions found in grassland and mangrove swamp ecosystems?" Students need to survey the population, community, and types of interaction

in these two ecosystems to answer this question. Activities such as field trips allow students to view, record, analyze, and draw conclusions from the results of observations.

In a similar vein, Laskowski et al. (2016) proposed that students learn best about wildlife habitat selection – the process by which animals decide where to live – through practical outdoor activities and discussions in the classroom. Students will understand more about the concept of science when they look at the real world than when they learn theoretically in the classroom. Indirectly, students are aware of and appreciate the beauty of nature that needs to be preserved. Singh et al. (2019) and Chin (2002) agreed that investigable questions allow students to collect data in an effort to find answers.

6.1.8 Problem-Solving Category

One student-generated question fell into the problem-solving category. Problem-solving category questions involve the implementation methods for solving a problem or issue (Chin & Kayalvizhi, 2002). This category of question differs from the design category in that the design question focuses on technology or product production (Kamarudin et al., 2022). Problem-solving questions encourage students to use their expertise to develop new methods to address challenges. Students need to identify problems or issues, define and explore appropriate methods, and test and reflect on those methods. The question a student in this study generated was “How can we identify and distinguish the properties of three unknown clear solutions?” First, students need to define what a “solution” is and explore the physical properties of solutions. Next, students need to identify physical characteristics such as pH value, density, and boiling point through experimentation.

Rillero et al. (2018) suggested an activity where the students could explain what it means for something to sink or float and how the more weight a boat has, the better it can float. However, Rillero et al.’s study was implemented for 7- to 9-year-old students. Therefore, the problem was given to the students using the problem-solving approach. Eventually, students in our study compared the differences between the three unknown clear solutions.

6.1.9 Validation of Mental Model Category

Students generated six questions in the validation of mental model category. Questions in this category involve the confirmation of a scientific concept through the construction of concrete materials (Chin & Kayalvizhi, 2002). By examining the structure of this actual material, students become more precise in their understandings of a concept. The validation of mental model questions formulated in this study were “How can a menstrual cycle model

be constructed?”, “How can a model of the digestive system be constructed?”, “How can the digestive system be modeled?”, “How can a green building model be constructed?”, “How can a model of global warming be constructed?” and “How can climate change be modeled?”

According to Prins (2020), a key criterion for investigable questions is that they should help one to understand how or why something works. Usually, the science involved is an abstract concept that cannot be seen with the senses, such as energy transformation. For the question “How can a green building model be constructed?” students could consider the components of green buildings, including energy efficiency, water efficiency, and waste reduction. Students could design a green building to answer the investigation questions. Hands-on activities would involve active learning that could increase students’ understanding. For example, if students used solar panels to generate electricity for green buildings, they could show the energy changes. Therefore, students’ understanding of science concepts could be strengthened. In a similar way, Buber and Coban (2020) proposed an activity based on the integration of modeling and science to answer a real-life question related to volcanism, which is a continuously unobservable but important phenomenon for many countries.

6.2 *The Nature of Non-Investigable Questions*

Non-investigable questions require answers in the form of basic information, complex information, and philosophical or religious questions. Basic information refers to essential information that must be known and can be easily obtained. These criteria also parallel those identified by Prins (2020) who mentioned that non-investigable questions can be directly addressed using books or online searches.. Singh et al. (2019) also offered a similar interpretation, stipulating that non-investigable questions are too simple, specific, and inconsequential to be investigable. Complex information requires explanations that are difficult to describe and sometimes beyond the ability of students to reflect upon. Usually, this type of question starts with “how” and “why.”

Six questions needed basic information in order to be answered: “What quantity of ice is needed to melt into 25 ml of water?”, “What is the function of the esophagus?”, “What is the meaning of food digestion?”, “What are some examples of polluted rivers in Malaysia?”, “What will happen to fish in a polluted river?” and “Why can solar energy save electricity?” Students only need to refer to one source, whether a textbook, reference book, search engine, or asking others and there is no debate on the solution. Six questions needed complex information to be answered. Questions included: “Why can a woman’s emotions interfere with her menstrual cycle?”, “Why does the menstrual cycle

happen?” and “Why does heat cause ice to melt?” The relationship between a woman’s emotional state and the menstrual period can be challenging to explain. Neither philosophical nor religious questions can be proven scientifically. These features involve a person’s belief system and are difficult to prove using logic.

7 Conclusions and Implications

In this study, the IQFT protocol was developed as a way to support students in formulating investigable questions. The IQFT protocol consisted of eight steps: (i) choosing a question focus, (ii) introducing the rules for questioning, (iii) generating questions individually, (iv) listing all questions, (v) introducing a rubric for grading investigable questions, (vi) grading the questions, (vii) arranging the investigable questions, and (viii) reflecting on and designing the investigation. Although formulating investigable questions is difficult and requires higher-order thinking skills, the key is practice using the IQFT protocol over time.

The findings of this study suggest that teachers need to provide many more examples of investigable questions than non-investigable ones. Investigable questions stimulate reasoning and critical thinking, prompting active cognitive and physical engagement. If necessary, a list of sample questions can be pasted in the lab or classroom so that students always remember these types of questions. Despite the group activities provided to actively engage students, some students still remained passive. For this reason, it is suggested teachers should remind students that producing questions is a learning process and that mistakes are not to be feared.

There were some limitations to this study. First, the sample size of 48 students limits the generalizability of the results. It is also challenging to gauge individual student improvement when class questions were viewed as a priority based on the SMART rubric. Additionally, the question focus was so general that was not effective in stimulating students to produce questions that can be investigated. Therefore, we would suggest that real-world examples and current situations should be used to spark curiosity and interest in a topic. Nevertheless, the IQFT protocol offers a springboard for science teachers to facilitate students’ generation of investigable questions. This in turn can be used to design experiments or to implement the highest level of inquiry-based science education: open inquiry.

This study contributes to existing literature and practice with particular regard to (a) guiding teachers on how to facilitate student questioning,

(b) providing a deeper understanding of the types of questions that students ask in science classrooms and how these questions contribute to their learning, and (c) offering insights into student thinking processes and how they make sense of science concepts. The study has particular relevance to the Malaysian secondary school context, as it addresses a key criterion of the Ministry of Education's curriculum – the development of questioning and critical thinking skills – and offers a clear strategy for training students to ask questions.

Abbreviations

DBR	Design-based Research
IQFT	Investigable Question Formulation Technique
SMART	Specific, Measurable, Achievable, Relevant, Timely

Acknowledgements

The authors would like to express our sincere gratitude to the first author's students who willingly participated in the study. Their dedication and hard work have provided valuable insights that greatly contributed to the development of the questioning protocol.

Ethical Consideration

Approval to conduct this study was granted by the Ethics Review Committee of the Educational Policy Planning and Research Division, Ministry of Education Malaysia (KPM.600-3/2/3-eras(7416)). The data collected from this study were obtained with the necessary clearance from the partner school, guardians, and the students involved in the study.

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