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Research article

STEM in chemistry: Cultivating problem-solving skills via blended problem-based learning Socratics module

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Abstract: The development of students' problem-solving skills is vital for cultivating a future-ready workforce, particularly in the domains of Science, Technology, Engineering, and Mathematics (STEM) education. Despite its importance, many students face difficulties in connecting classroom learning to real-world contexts, a challenge that is particularly pronounced in chemistry due to the abstract nature of concepts such as the three levels of chemistry representation (macroscopic, microscopic, and symbolic). The integration of STEM principles into teaching approaches, such as the blended problem-based learning (BPBL) approach, which combines face-to-face and online learning, has shown promise in bridging this gap. By incorporating elements of STEM into the BPBL approach, this study explores how these disciplines can enhance problem-solving skills and facilitate deeper understanding. Specifically, this research investigates the effect of the BPBL_S Module—a module that integrates BPBL with the Socratic method—on students' problem-solving abilities in the three representation levels of chemistry concept. Employing a design and development research approach, the study involved 25 students and one teacher, selected through clustered random sampling. Data were collected through observations, student documents, and interviews, and were analysed thematically. The findings suggest that the BPBL_S Module significantly improves students' problem-solving skills by enabling them to apply STEM concepts to chemistry, thus enhancing their ability to justify solutions comprehensively across macroscopic, microscopic, and symbolic levels. This study underscores the potential of the BPBL_S Module as an effective STEM-based teaching aid to better prepare students for the problem-solving demands of the future workforce.

Keywords: three representation levels of chemistry, problem-solving, problem-based learning, blended problem-based learning, blended problem-based learning Socratics

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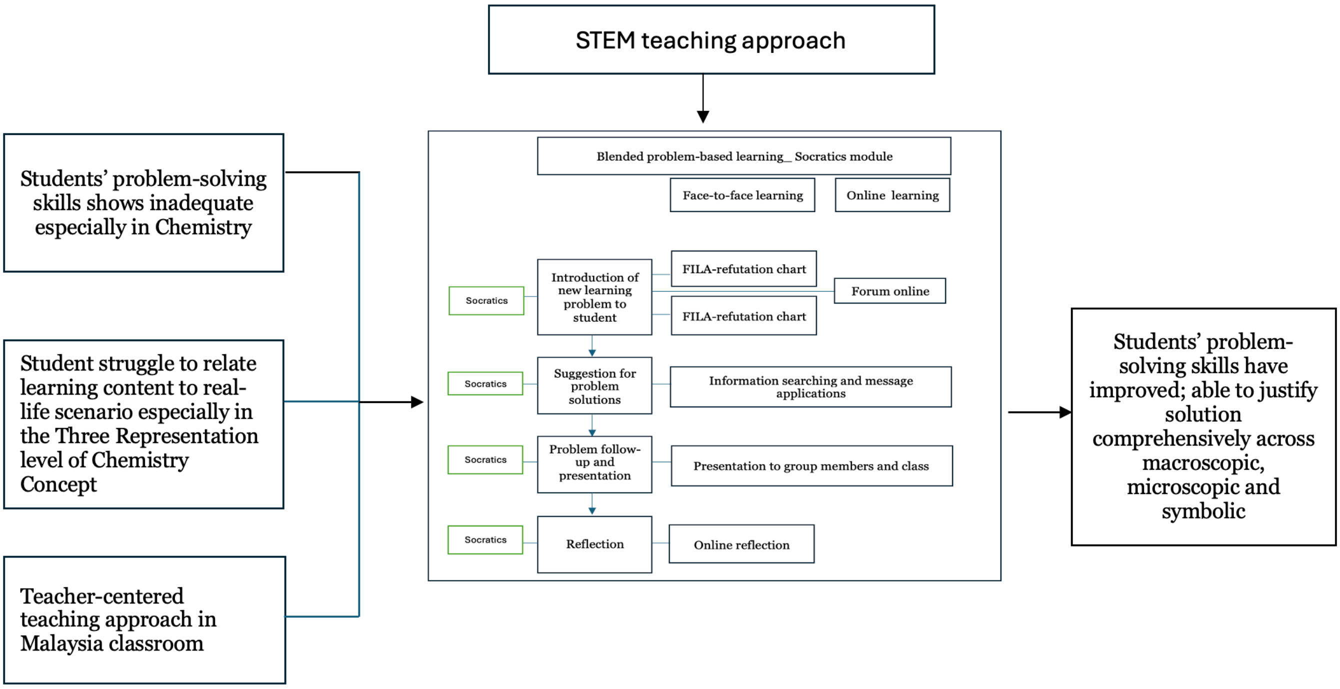


1 Introduction

One of the key objectives of the Program for International Student Assessment (PISA) is to evaluate students' ability to integrate scientific concepts learned into everyday life, a crucial aspect of STEM education (OECD, 2023). According to the OECD 2023 report, Malaysian students' performance in PISA lags significantly behind that of students from other developed countries, as evidenced by Malaysia's rank of 49 out of 81 countries. This underwhelming performance suggests that many Malaysian students struggle to apply STEM principles—specifically, the integration of Science, Technology, Engineering, and Mathematics concepts—into real-life scenarios, which hinders their mastery of problem-solving skills. These skills are a critical focus of the Malaysian Education Blueprint 2013-2025, emphasising the importance of STEM literacy in preparing a future-ready workforce (Ministry of Education Malaysia, 2012).

Chemistry, a core STEM discipline, involves abstract concepts that require students to integrate these principles into their daily lives effectively. Ideally, chemistry education should utilise 21st-century student-centered learning approaches that emphasise the application of STEM concepts. However, in practice, teacher-centered approaches still dominate in Malaysia, posing a significant impediment to the development of both chemistry concepts and problem-solving skills (Raman et al., 2024). One of the major challenges is students' mastery of the three representation levels of chemistry—macroscopic, microscopic, and symbolic (Sun et al., 2024; Talanquer, 2022). Previous studies have highlighted that poor students' involvement in the learning process often leads to inaccurate construction of these complex concepts (Atikah et al., 2021). Active involvement is essential in helping students link the macroscopic with the microscopic and the microscopic with the symbolic levels, which are foundational to STEM education (Savasci-Acikalin, 2019).

Problem-based learning (PBL) has been proven to enhance the learning of the three representation levels of chemistry Concept (Fibonacci et al., 2021). The problem-solving process central to PBL aligns with the real-world challenges students will encounter in the workforce, where a deep understanding of STEM concepts is essential (Hmelo-Silver, 2004; Raman et al., 2024). Throughout the problem-solving process, students are expected to utilise higher-order thinking skills—such as application, analysis, and evaluation—to generate effective solutions to real-life problems, thereby fostering the essential STEM competencies (Ibrahim et al., 2022).

According to Ibrahim et al. (2022) and Suhadi et al. (2021), there are obstacles to PBL implementation, particularly in monitoring large class sizes. Blended problem-based learning (BPBL) offers an alternative by combining online and face-to-face learning modes, extending the learning process beyond traditional classroom boundaries and embedding STEM learning in various contexts (Li & Sitthiworachart, 2024; Shimizu et al., 2019). While BPBL has been shown to help students overcome misconceptions and answer questions effectively, it has been observed that students still struggle to provide detailed justifications for their solutions—a critical component of STEM problem-solving (Atikah et al., 2021; Ibrahim et al., 2022).

This issue arises because students are less likely to apply the critical argumentation process that is required for successful problem-solving in STEM settings (Abror et al., 2024; Hmelo-Silver, 2004). Students who actively participate in argumentation can exchange ideas, identify and correct mistakes, and generate solutions based on pertinent and convincing arguments (Kim et al., 2021). The Socratic method, an approach aligned with STEM principles, can enhance these argumentation activities by encouraging students to think critically and justify their answers (Raju et al., 2023). This method, when integrated with BPBL to form the blended problem-based learning Socratic (BPBL_S) approach, has the potential to improve students' active engagement and their ability to provide detailed justifications, thereby strengthening their STEM competencies.

Building on this, the blended problem-based learning Socratic (BPBL_S) Module for the three representation levels of chemistry concept was developed. Consequently, this study aims to address the following research questions:

1. How can the BPBL_S Module enhance students' problem-solving skills at the macroscopic level in the three representation levels of chemistry concept?
2. How can the BPBL_S Module enhance students' problem-solving skills at the microscopic level in the three representation levels of chemistry concept?
3. How can the BPBL_S Module enhance students' problem-solving skills at the symbolic level in the three representation levels of chemistry concept?

2 Literature review

2.1 The principle and concept of STEM education

STEM education, an acronym for Science, Technology, Engineering, and Mathematics, is a pedagogical approach that integrates these disciplines into a cohesive learning paradigm based on real-world applications (Utami et al., 2020). The core principle of STEM is to nurture problem-solving and innovation by encouraging students to see the interconnectedness of these fields, thereby preparing them for the multifaceted challenges they will face in their careers and everyday lives (Fadzli et al., 2019). STEM education emphasises active, experiential learning, which aligns closely with problem-based learning (PBL). PBL places students in real-world scenarios, requiring them to engage deeply with content, collaborate with peers, and develop solutions to complex, open-ended problems (Hmelo-Silver, 2004; Raman et al., 2024). This approach is integral to STEM because it mirrors the iterative, exploratory processes used in scientific research and technological development (Kurniati et al., 2021). With the rapid advancement of technology in education, particularly in the post-pandemic era, the integration of face-to-face and online learning—known as blended problem-based learning (BPBL)—emerges as an ideal solution to overcome the inherent limitations of traditional problem-based learning (PBL).

2.2 Blended problem-based learning (BPBL)

Blended problem-based learning (BPBL) is a PBL approach that integrates face-to-face and online learning modes (Amin et al., 2021; Ibrahim et al., 2022; Shimizu et al., 2019). In STEM education, where practical applications of scientific, technological, engineering, and mathematical concepts are essential, this dual learning approach is especially well-suited. By involving students in addressing challenging, real-world problems that frequently have numerous answers, BPBL fosters active, student-centered learning and reflects the type of multifarious problem-solving needed in STEM areas (Li & Sitthiworachart, 2024; Raman et al., 2024). This approach incorporates viewpoints from a number of constructivist and cognitive theorists, such as Piaget, Jerome Bruner and Vygotsky (Rannikmäe et al., 2020).

Piaget (1976) emphasised how crucial it is to build knowledge from students' existing understanding. In line with this viewpoint, the BPBL approach requires students to assess and analyse their prior knowledge (existing knowledge) in order to find any gaps that are known as learning issues (Atikah et al., 2021; Ibrahim et al., 2022). According to Jerome Bruner, a questioning method like the Socratic method can greatly improve students' recognition of their prior knowledge (Rannikmäe et al., 2021; Suhadi et al., 2021). Leveraging this potential, the blended problem-based learning Socratics (BPBL_S) module incorporates the Socratic method within the BPBL approach. This integration sets the BPBL_S module apart from others by enabling the early correction of prior knowledge that might not be consistent with scientific understanding.

Vygotsky (1978) asserted that students' experiences and interactions with their environment shape their knowledge. This interaction concerns social interactions between students (student-student) and between teachers and students (teacher-student). Through social interaction, students can attain the Zone of Proximal Development (ZPD), which is the gap between what they can achieve on their own and what they can accomplish with help (scaffolding) from peers or teachers (Vygotsky, 1978). The BPBL increases student interaction with the environment by fusing online and face-to-face learning modes. The Socratic method, which seeks to develop students' capacity for justification, can be used to further enhance scaffolding activities by questioning activities.

Previous research has highlighted that the BPBL is an ideal strategy to leverage the strengths and reduce the limitations of each learning mode (Li & Sitthiworachart, 2024; Yun et al., 2023). Regardless of the growing prevalence of online learning, face-to-face learning mode remains important because it provides direct supervision and immediate support to students (Atikah et al., 2021; Ibrahim et al., 2022). However, online learning provides major advantages in terms of monitoring student progress and engagement (Ibrahim et al., 2022). In Malaysia, where large class sizes pose a major challenge to the implementation of PBL that emphasises small-group teaching, online learning platforms offer an alternative to the problem.

Teachers are able to manage larger groups of students simultaneously via online learning platform (Yun et al., 2023). In addition, asynchronous discussion forums in this online learning platform allow students to reflect and express their ideas more thoroughly, which is crucial for developing problem-solving skills that are important in STEM education (Xie & Correia, 2024). Additionally, the integration of online learning gives students access to a variety of knowledge sources, regardless of time or location restrictions, giving them even more freedom to study material whenever it suits them (Szymkowiak et al., 2021).

2.3 BPBL integrates with Socratics method in BPBL_S Module

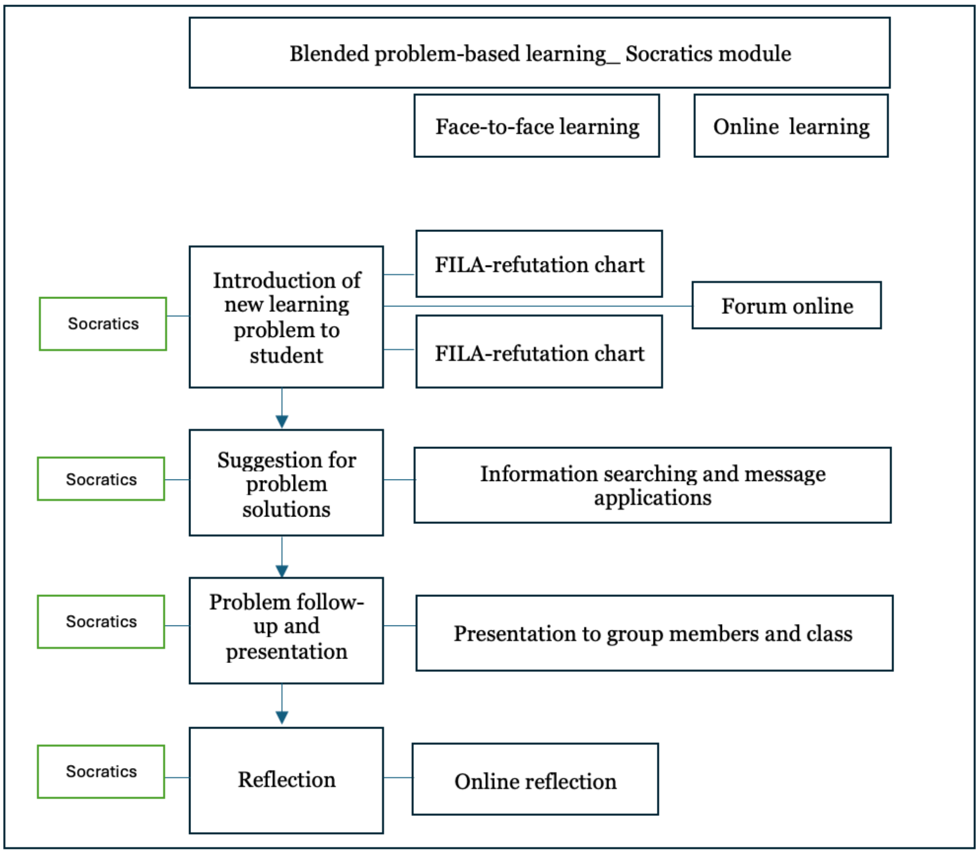
Despite the advantages of the BPBL approach, studies has shown that students frequently unable to provide detailed justifications for their solutions, which is an essential component of effective problem-solving in STEM areas (Atikah et al., 2021; Ibrahim et al., 2022). This limitation highlights the need for a more refined approach that actively encourages students to engage in rigorous argumentation and justification—core STEM competencies required for developing strong, evidence-based solutions to complex problems (Hmelo-Silver, 2004; Shimizu, 2019).

To close this gap, the blended problem-based learning Socratic (BPBL_S) module, which integrates the Socratic method within the BPBL framework, represents a possible improvement. The Socratic method, which consists of probing questions designed to stimulate critical thinking and elucidate underlying assumptions, assists students in better articulating and defending their reasoning—a skill that is critical in STEM disciplines where solutions must be thoroughly justified (Dalim et al., 2022; Raju et al., 2023). The BPBL_S Module improves students' grasp of STEM concepts as well as their ability to produce and justify comprehensive solutions by encouraging deeper involvement in the problem-solving process.

2.4 BPBL_S learning strategy

The BPBL_S learning strategy has been developed by adapting the PBL model by Hmelo-Silver and Ferrari (1997) as illustrated in Figure 1. This strategy comprises four phases: (i) the introduction of new learning problem, (ii) suggestions for problem solutions, (iii) problem follow-up and presentation, and (iv) reflection.

Figure 1. Blended problem-based learning Socratics module learning strategy



Referring to Figure 1, in phase 1, students are required to form small groups and subsequently assign tasks to each group member. There are four primary roles for each group member: (i) group leader, (ii) secretary, (iii) recorder, and (iv) observer. Each group is then given a problem to solve. Students analyse the problem and organise facts, ideas, issues, and learning actions into a table known as the FILA-refutation chart (fact, idea, learning issue, and action) as shown in Table 1. The FILA-refutation chart acts as a graphic organiser to assist in organising students' thoughts as a preliminary step in the problem-solving process (Hmelo-Silver, 2004; Hmelo-Silver & Ferrari, 1997).

Table 1. FILA-refutation chart

Fact	Idea			Idea (refutation)			Learning issue	Learning issue (refutation)	Action	Action (refutation)
	Macroscopic	Microscopic	Symbolic	Macroscopic	Microscopic	Symbolic				

In contrast to previous studies in Atikah et al., (2021) and Ibrahim et al., (2022), this study has improved the existing FILA chart by integrating the Socratic method. This enhancement involves adding a "refutation" column to the existing columns for ideas, learning issues, and actions. This refutation column is filled out only after students engage in an online discussion forum involving the entire class. The definitions of each component in the FILA-refutation chart are as follows:

Table 2. Explanation of FILA-refutation chart

Column	**Explanation**
Facts	Explicit facts derived from the given problem scenario
Idea (macroscopic)	Anything related to the given problem, including hypotheses and phenomena within the problem.
Idea (microscopic)	Related to the Particulate Theory of Matter, which includes atoms, molecules, and ions (if applicable)
Idea (symbolic)	Related to symbols such as chemical formulas and chemical equations
Learning issue	Questions that need to be answered or issues for which the answers are unknown
Action	The methods, activities, or approaches that need to be implemented to address the learning issue
Refutation column	All aspects related to macroscopic, microscopic, and symbolic ideas, learning issues, and actions have been refined following discussions in the online discussion forum

Students discuss within their respective groups to complete the FILA-refutation chart. During these discussions, the Socratic method is emphasised through questions posed by both teachers and students. Once each group has completed their FILA-refutation chart, they upload it to the online discussion forum. Unlike the previous steps, this step involves cross-group discussions among all students. Following the completion of the online discussion, students use feedback from other groups to refine their ideas, learning issues, and actions and amend them in the "refutation" column of the FILA-refutation chart (Table 1). Students then distribute the learning issues among group members for resolution.

Next, in the problem follow-up and presentation phase, students gather information to resolve the learning issues identified in the previous phase. Students can access material from print and electronic media, especially the Internet. The deluge of information available on the Internet requires students to ensure accuracy by obtaining information from only reliable sources (Tolu et al., 2018). After students have resolved each learning issue, they present their solutions within their groups. Subsequently, after determining the best solution to the given problem, each group presents their findings in front of the class. This phase is conducted face-to-face.

At this phase, students must evaluate their peers' understanding of the presented solutions and justify their answers to questions posed by other students. Evaluation in this context is divided into three skills which are: (i) identifying strengths and weaknesses in the proposed solutions, (ii) providing constructive feedback supported by evidence or relevant concepts and (iii) engaging in comparative analysis, where students contrast different solutions to enhance their understanding.

In contrast, justification involves students presenting and defending their solutions or responses to questions using: (i) scientific evidence (e.g., chemical equations), (ii) logical reasoning that connects the problem context with theoretical principles and (iii) iterative refinement of answers based on peer feedback. After determining the best solution, they reflect on the problem-solving process that they have experienced. Reflection entails students analysing their learning experiences to: (i) identify successful strategies and areas for improvement, (ii) connect theoretical knowledge to practical scenarios and (iii) develop transferable skills for solving new and unfamiliar problems.

The Socratic method has been systematically integrated into every phase of the BPBL_S Module (refer to Figure 1). This module was developed based on the BPBL_S Strategy and implemented via the Google Classroom Platform; a free platform provided by the Ministry of Education Malaysia to all teachers. This article discusses two specific modules: Module 1, which addresses the problem of stomach ache, and Module 2, which focuses on the issue of acid rain. Detailed descriptions of both problems are available in Appendix A. Module 1 includes a set of guiding questions designed to assist teachers in applying the Socratic method, whereas Module 2 does not include such guiding questions.

2.5 Three representation levels of chemistry concept

The mastery of chemistry, a core STEM discipline, requires a deep understanding of the three representation levels: macroscopic, microscopic, and symbolic (Gilbert & Treagust, 2009; Johnstone, 2000). The macroscopic representation level includes phenomena that can be seen, touched, or smelt (Dori & Hameiri, 2003; Gilbert & Treagust, 2009). Colour changes noticed during chemical reactions are an example of such phenomena. The microscopic representation level focuses on particles, such as atoms, molecules, and ions (Chittleborough, 2014), whereas the symbolic representation level includes chemical formulas and equations that represent these microscopic entities (Johnstone, 2000). Understanding the three representation levels of chemistry concepts is pivotal in gaining a comprehensive mastery of chemistry (Gilbert & Treagust, 2009; Johnstone, 2000). As a result, this concept should be emphasised from the beginning of chemistry education (Dori & Hameiri, 2003; Gkitzia et al., 2020; Johnstone, 2000).

The integration of the BPBL Module with the Socratic method offers tremendous potential in enhancing students’ ability to connect these representation levels. By engaging with real-life problems, students are able to connect abstract, microscopic concepts with tangible, macroscopic phenomena, while mastering the symbolic language of chemistry (Gilbert & Treagust, 2009; Johnstone, 2000). This comprehensive approach not only improves students' conceptual comprehension but also provides them with the problem-solving abilities required for success in STEM disciplines. However, previous research has demonstrated that students were frequently unable to articulate extensive justification for their solutions, resulting in insufficiently detailed problem resolutions (Ibrahim, 2018).

Thus, the BPBL_S Module addresses this challenge by encouraging deeper engagement with the material using the Socratic method, thereby improving students' ability to articulate and defend their reasoning—a critical skill in both chemistry and other STEM disciplines (Dori & Hameiri, 2003; Gkitzia et al., 2020). Through recurrent discussion, they deepen their understanding by coherently connecting these levels together. Reflection activities help to strengthen this understanding. Students assess their ability to transition smoothly across representation levels. For example, a student might reflect: "Visualising the ionisation of HCl at the microscopic level helped me understand its symbolic representation and its role in macroscopic phenomena like gastric acid neutralisation."

3 Methodology

3.1 Research design

This study employed the design and development research (DDR) methodology as outlined by Richey and Klein (2005). The DDR approach was selected for its comprehensive framework, which encompasses three key phases: (i) needs analysis, (ii) design and development, and (iii) evaluation of the developed product (Alias et al., 2014). This article specifically concentrates on the evaluation phase, focusing on assessing the impact of the BPBL_S Module on enhancing students' problem-solving abilities within the three representation levels of chemistry concept. However, the first two phases—(i) needs analysis and (ii) design and development—are briefly discussed to provide an overview of the BPBL_S Module development process before a comprehensive evaluation is conducted.

The need analysis phase was conducted to achieve two primary objectives: (i) to identify students' mastery level of the three representation levels of chemistry concepts and (ii) to identify the current implementation of the problem-based learning approach. Students’ mastery levels were assessed through the three representation levels of chemistry concept test, involving 82 form four students (16 years old) from two districts in Perak. The researcher self-developed the test questions and demonstrated high validity and reliability. The findings revealed that students’ mastery of the three representation levels of chemistry concepts was low. Students struggled with transitioning between macroscopic, microscopic, and symbolic representation levels. This outcome emphasises the need to introduce instructional approaches such as the BPBL_S Module, which has the potential to improve students' mastery of problem-solving processes for this concept.

Meanwhile, to identify the current state of problem-based learning (PBL) implementation, 63 teachers from two districts in the state of Perak were selected as the sample. For this purpose, a questionnaire was developed by adapting instruments from previous researchers, including Ab Hakim and Iksan (2018), Yee et al. (2017), and Zainal Abidin and Osman (2017). The questionnaire employed three constructs: (i) teacher’s knowledge level of PBL, (ii) teacher’s understanding level of PBL, and (iii) the implementation level of PBL. Teachers need to evaluate themselves towards the three constructs with a four-point Likert scale. Overall, the teachers had a good knowledge of PBL (Mean=3.51, SD=0.79), but a moderate understanding of PBL (Mean=3.36, SD=0.92). Similarly, PBL implementation in schools was evaluated as modest (mean=3.44, SD=0.86). Time restrictions are a key barrier to the widespread application of PBL in school.

This is evident as, with a mean score of 3.00, only 21 teachers believed that they had enough time to implement PBL in classrooms. The brief length of teaching and learning sessions is one of the main issues associated with time restrictions (Ghufron & Ermawati, 2018; Raman et al., 2024). This problem arises because schools usually only allot 30 minutes for each session, which is not enough time to fully execute the PBL approach. While, PBL will take about a few weeks on average to execute well.

To address the challenge of time restrictions for implementing PBL in schools, Ibrahim and Jamaludin (2019), along with Raman et al., (2024), proposed adopting a blended learning approach (integrates online and face-to-face learning modes) to the conventional PBL (face-to-face). This approach allows teaching and learning sessions to extend beyond school hours through online platforms, effectively mitigating the restriction of short instructional periods during school hours (Ibrahim & Jamaludin, 2019). For instance, students can analyse and evaluate questions asynchronously through online discussion forums before providing their responses.

The second phase of the study concentrated on designing and developing the blended problem-based learning Socratic module (BPBL_S). The main purpose of this phase was to develop a problem-based learning module for form four students, that focused on the three representation levels of chemistry concepts, with experts’ feedback. This phase was divided into two steps: (i) designing the module and (ii) developing the module. Individuals interview using a semi-structured interview protocol was employed during the module design step to establish: (i) learning objectives, (ii) learning content, (iii) teaching methods, and (iv) assessment strategies, as outlined by Abdullah et al., (2022). In total, nine experts participated in the interview session, comprising three experts in chemistry education, three experts in PBL, and three experts in the Socratic method. The selection of these experts was based on predefined criteria, as detailed in Table 3.

Table 3. The expert's criterion

Field	Expert criterion
Chemistry education	Experienced in secondary school education for Form 4 and 5 chemistry subjects.
Socratic method	i. Experienced in the Socratic field. ii. Active in research in the Socratic method.
Problem-based learning	i. Experienced in problem-based learning. ii. Active in research related to problem-based approaches.

By applying the thematic analysis, key themes identified from expert feedback formed the basis for the module's structure. Overall, the findings from the expert interviews are presented in Table 4.

Table 4. Findings from experts' interview

Aspects in the module	Interview finding
Learning objectives	Content standard of 6.7 (Neutralisation)
Learning strategies	BPBL_S Module criterion i. Student-centered learning ii. Need to stimulate students to think, remember and look for solutions. iv. Need to enhance brainstorming among students.
Learning assessments	The assessment in this module encompasses three stages, namely: i. Assessment of the solution to learning issues ii. Assessment of the solution to the given problem iii. Overall reflection

The module was subsequently developed based on the findings from the interviews. Upon completion of the module, three experts were appointed to validate the BPBL_S Module. It was found that the module demonstrated high validity in terms of the content of chemistry, the PBL, and the concept of the Socratic method. The next phase is the evaluation phase. This article specifically focuses on the evaluation phase, with an emphasis on assessing the impact of the BPBL_S Module in enhancing students' problem-solving abilities within the three representation levels of chemistry concept.

3.2 Research participants

To investigate the effects of implementing the BPBL_S Module, a cluster random sampling method was utilised. The sample comprised Form 4 students from a school in Perak, Malaysia. The state of Perak was selected due to its comparatively low academic performance in chemistry, as indicated by the 2020 Sijil Pelajaran Malaysia (SPM) results, where the Gred Purata Mata Pelajaran (GPMP) for chemistry was 5.02, falling below the national average of 4.89 (Ministry of Education Malaysia, 2020). From the overall student population in Perak, the district with the lowest GPMP was identified, and one school from this district was randomly selected. Following the method suggested by Chua (2010), the names of all schools within the district were written on individual slips of paper, which were then rolled up and placed in a jar. A single slip was drawn to determine the selected school.

Subsequently, the researcher contacted the selected school, explained the research objectives, and obtained consent from the school's teacher, ensuring that the natural setting of the student's learning process was preserved, as emphasised by Creswell (2013). A total of 25 students were then divided into five groups. For ease of data collection, each student was provided with a name tag indicating their group and their position within the group (e.g., the first student in the first group received a tag labelled A1, where 'A' denotes the group and '1' signifies their position within that group).

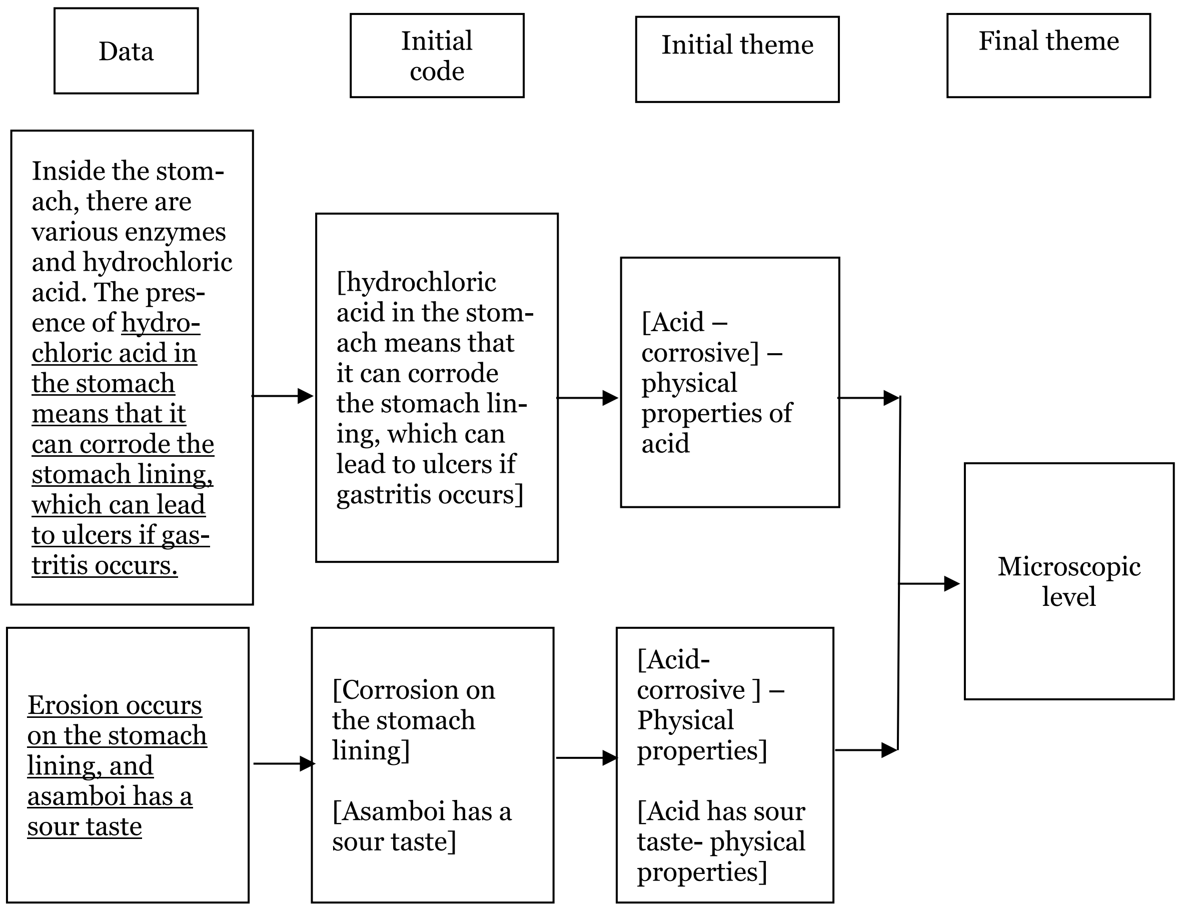
3.3 Data collection and analysis

Data were collected from three primary sources: (a) in-class observations, (b) students' documents, and (c) semi-structured interviews. To ensure an unbiased analysis and preserve the authenticity of the learning environment, researchers acted as non-participant observations (Creswell, 2013). During these observations, both general information (such as physical settings, time, date, and attendance) and detailed data (including precise timings, researchers' observations, and students' verbal interactions and interpretations) were meticulously recorded (Creswell, 2013; Ho, 2008). Additionally, the teaching and learning processes were documented using a video recorder, which allowed for a comprehensive review and analysis of students' verbal and non-verbal behaviours (Haidet et al., 2009).

In the analysis of students' documents, two critical documents were collected and analysed: (i) FILA-Refutation Chart and (ii) solutions to the learning issues. Meanwhile, semi-structured interviews were conducted to obtain detailed information about the learning process that could not be captured through observation and analysis of student documents (Chua, 2010). For example, the researcher interviewed a group of students who had altered their group's responses in the 'refutation column' of the FILA-Refutation Chart, specifically regarding ideas, learning issues, and actions.

Data from all instruments were analysed using the thematic analysis approach as described by Braun and Clarke (2006). The process began with the transcription of data from each instrument. Once the transcripts were prepared, the data were read multiple times to identify key ideas. In the second step, initial codes were identified through a thorough analysis. These codes were then grouped into initial themes in the third step. The fourth step involved reviewing and refining these themes, where similar themes were combined to form final themes. In the fifth step, the researcher defined and refined the final themes by examining the relationships between them. Finally, in the sixth step, the researcher presented the data in the form of narratives or graphics as in Figure 2.

Figure 2. An example of thematic analysis of data



In qualitative research, validity and reliability are referred to as trustworthiness or credibility (Creswell, 2013). Credibility in the analysis of research findings can be established through various methods, including (i) triangulation of data and (ii) external auditing. In this study, data from observations, documents, and interviews were triangulated to ensure comprehensive findings. Data triangulation was employed to strengthen the findings obtained through various data collection techniques, as described by Creswell (2013) and Merriam (2009). Figure 3 illustrates an example of data triangulation, which combines data from documents (the FILA refutation chart) and interview data. For instance, the analysis of the FILA chart could identify changes made by students in the macroscopic idea, as compared to the macroscopic idea (refutation), as shown in Table 5. However, it did not provide insight into the reasons behind these changes. Interview data were subsequently used to gain a more detailed understanding of the student's motivations for making these changes.

Figure 3. Example of data triangulation

FILA refutation chart (Module 1)

Fact	Idea			Idea (refutation)		
	Macroscopic	Microscopic	Symbolic	Macroscopic	Microscopic	Symbolic
Stomach ache	Hydrochloric acid, enzyme	The substance in the stomach	HCl	There is erosion on the wall of the stomach	In the water, there is a hydrogen ion, H+ which reacts with Chlorin, Cl	$HCl \rightarrow H^{+} + Cl^{-}$
Assamboi	Symptoms of gastric patients	Glycyrrhizin acid	$C_4H_{62}O_{16}$	Asamboi has a sour taste	Citric Acid consists of hydrogen ion	$C_6H_8O_7$

Interviewer : In the macroscopic idea column, your group initially wrote "hydrochloric acid, enzyme." However, after discussions with peers from other groups and the teacher (refutation), you changed the idea to "erosion on the wall of the stomach". Could you explain this? [TSB11M1S2]

A1 : After discussing with friends from other groups and the teacher, we found that the stomach ache experienced was due to gastric. This gastric is caused by erosion in the stomach, resulting from acid. [TSB1A1M1J2]

Interviewer : Which part of the stomach experiences erosion? [TSB1A1M1S3]

A1 : Erosion occurs on the stomach lining when the stomach becomes overly acidic. [TSB1A1M1J3]

Additionally, the researcher sought validation of the identified themes from two experts, employing a method known as external audit (Creswell, 2013), please refer to Appendix B for an example of expert feedback. The criterion used in order to select the experts is the same as in Table 3.

4 Results and discussion

The findings will be explained in sequence according to the phases of the BPBL_S learning strategy. The discussion will begin with Module 1 and will be followed by Module 2.

4.1 Problem-solving skills at macroscopic level in three representation levels of chemistry

The implementation of the BPBL_S Module facilitates students' ability to identify and justify chemical concepts through problem-based scenarios, particularly in the context of acids and bases. Students are better equipped to apply theoretical knowledge to practical, everyday situations by integrating real-life scenarios, such as the stomach ache problem presented in Module 1 (Witri et al., 2023). This is one of the key advantages of BPBL, which highlights the integration of real-life problems into the learning process (Costa et al., 2023; Raman et al., 2024). It empowers students to link between macroscopic representations (tangible, visible phenomena) and the abstract concepts being studied, thereby advancing a deeper understanding of the three representation levels of chemistry concept. These findings are consistent with the research by Costa et al. (2023), which emphasises the efficacy of real-world-related learning approaches like BPBL in facilitating comprehensive understanding across macroscopic, microscopic, and symbolic levels in STEM education.

Furthermore, the online discussion forum integrated into the BPBL_S Module promotes class-wide interactions, which is a significant improvement over the traditional PBL model, which often limits conversations to small groups of 4-5 students (Atikah et al., 2021; Hmelo-Silver, 2004). This broader forum fosters enhanced engagement through the Socratic method, where students from various groups pose questions to each other. This interaction supports the refinement of macroscopic concepts, particularly in the 'refutation' section, as illustrated in Table 5.

Table 5. Completed FILA-refutation chart after online forum discussion in Module 1

Fact	Idea			Idea (refutation)			Learning issue	Learning issue (refutation)	Action	Action (refutation)
	Macroscopic	Microscopic	Symbolic	Macroscopic	Microscopic	Symbolic				
Stomach ache	Hydrochloric acid, enzyme	The substance in the stomach	HCl	There is erosion on the wall of the stomach	In the water, there is a hydrogen ion, H^+ which reacts with Chlorin, Cl	$HCl \rightarrow H^+ + Cl^-$	What is the treatment for gastric patients?	Do gastric patients experience stomach erosion?	Health portal	http://hello-doctor.com
Asamboi	Symptoms of gastric patients	Glycyrrhizin acid	$C_4H_62O_{16}$	Asamboi has a sour taste	Citric acid consists of hydrogen ion	$C_6H_8O_7$	Does asamboi affect the human digestive system?	What is the connection between the stomach pain experienced and asamboi?	http://pubmed.ncbi.nlm.nih.gov/8386690	http://www.smj.org.sg/sites/default/files/4702/4702cr2.pdf

Based on Table 5, initially, in their respective groups, students listed macroscopic ideas such as “Hydrochloric acid, enzymes, and symptoms of gastric patients”. However, after engaging in online discussions through the Socratic method, students revised these macroscopic ideas to include the “erosion on the wall of the stomach” and “Asamboi has a sour taste”. This change is supported by the findings from the interview analysis, which indicated that the improvement resulted from students observing other groups' FILA-refutation charts, discussing with their group members, and elaborating on the macroscopic ideas, as illustrated in the following interview excerpt.

Interviewer : In the macroscopic idea column, your group initially wrote "hydrochloric acid, enzyme." However, after discussions with peers from other groups and the teacher (refutation), you changed the idea to "erosion on the wall of the stomach”. Could you explain this? [TSB11M1S2]

A1 : After discussing with friends from other groups and the teacher, we found that the stomach ache experienced was due to gastric. This gastric is caused by erosion in the stomach, resulting from acid. [TSB1A1M1J2]

Interviewer : Which part of the stomach experiences erosion? [TSB1A1M1S3]

A1 : Erosion occurs on the stomach lining when the stomach becomes overly acidic. [TSB1A1M1J3]

These interview excerpts demonstrate that the Socratic method, combined with class-wide discussions, significantly enhances students' ability to elaborate on macroscopic ideas. This refinement not only aids in identifying learning issues more efficiently but also saves time in gathering information to solve the given problems—an important consideration given the challenges of implementing BPBL in schools (Atikah et al., 2021; Ibrahim et al., 2022).

In contrast, Module 2 did not provide specific guiding questions for teachers and students during BPBL_S sessions. Nevertheless, students were able to elaborate on macroscopic ideas through questioning activities during the online discussions, suggesting mastery of the questioning techniques introduced in Module 1. This is evidenced by the online discussion forum excerpts shown in Figure 4.

Figure 4. Example excerpt from online discussion forum at the macroscopic level for Module 2

D5: Are you sure that plants are decreasing because of the haze? What's the evidence? Does the haze affect plant respiration?

F5: What is the relationship between haze and the reduction of plants?

A2: Yes, they are affected due to the lack of sunlight for carrying out the photosynthesis process

A2: Because haze can cause soil to become acidic thus plants can live

D2: Haze causes soil become acidic?

B2: The soil is acidic due to acid rain, which is formed from harmful gases such as sulphur dioxide and nitrogen oxides released during forest fires. These gases then convert into sulfuric acid and nitric acid in the rainwater.

D5: Haze is also a pollution phenomenon, so is haze really the cause of acid rain?

B2: No, we will use acid rain as a pollution phenomenon, which causes the soil to become acidic and prevents plants from growing healthily because the acid rain consists of sulfuric and nitric acid droplets

D2: What happens to the soil when acid rain falls on it?

A2: The deposition of wet acid occurs. When wet acid deposition happens, it is already known that there are hydrogen ions in the acid, which disrupt the nutrients in the soil, lowering the soil's pH and making it more acidic.

Figure 4 illustrates that the questions posed by students D5, F5, and D2 enabled student A2 to provide a detailed response to the given problem. Initially, student A2 identified the concept being tested as related to the lack of sunlight for plants to perform photosynthesis, stating “They are affected due to the lack of sunlight for carrying out the photosynthesis process.” However, through the Socratic method and subsequent questioning, student A2’s understanding evolved, enabling a deeper analysis “...when deposition acid occurs, hydrogen ions present in the acid which disrupt the nutrients in the soil, lowering the soil’s pH value and making it more acidic”. This example underscores the strength of the Socratic method in enabling students to develop a deeper understanding of complex concepts through iterative questioning and dialogue (Dalim et al., 2022). The asynchronous nature of the online discussion forum supports this learning process by giving students time to contemplate and discuss problems before presenting their refined answers (Xie & Correia, 2024). This process allows students to update their answers in the FILA refutation chart to new responses in the refutation column, as shown in Table 6.

Table 6. Completed FILA-refutation chart after online forum discussion in Module 2

Fact	Idea			Idea (refutation)			Learning issue	Learning issue (refutation)	Action	Action (refutation)
	Macroscopic	Microscopic	Symbolic	Macroscopic	Microscopic	Symbolic				
The villagers' crop yield has been found to be decreasing	The number of plants is decreasing due to the haze	Plants require water molecules and carbon dioxide	$6O_2$ + 12 H_2O + solar energy → $C_6H_{12}O_6$ + $6O_2$ + $6H_2O$	Soil become acidic	The molecules of carbon dioxide, nitrogen oxide, and sulfur dioxide The high concentration of hydrogen ions	NO_2, SO_2, $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$	What is causing the decline in plant populations	What exactly happened to the soil?	From the internet, http://www.kompas.com/skola/rendah/2019/12/13/15000002/memahami-proses-dan-reaksi-kimia-fotosintesis	Surfing acid rain website

From the FILA-refutation chart above, students initially identified the macroscopic idea as "The number of plants is decreasing due to the haze." However, after engaging in discussions through the online forum, students revised this idea to a more accurate one: "Soil becomes acidic." Here, it is evident that students were able to link soil acidity to the effects of acid rain. This iterative process is reflected in the FILA-refutation chart (Table 6), where students revised their initial macroscopic ideas about plant health and soil acidity after engaging in forum discussions. The BPBL_S Module thus fosters a collaborative learning environment that enhances students' problem-solving skills by encouraging critical reflection and continuous refinement of ideas, consistent with the findings of Pimdee et al. (2024).

These findings demonstrate that the integration of the Socratic method via the BPBL_S Module enriches students' engagement and understanding, particularly in the context of chemistry education. The enhanced class-wide discussions and the ability to reflect on and refine concepts contribute to a more profound comprehension of the three representation levels in chemistry concept, ultimately cultivating students' problem-solving skills within STEM education.

4.2 Problem-solving skills at microscopic level in three representation levels of chemistry

The implementation of the BPBL_S Module has significantly enhanced students' ability to generate accurate ideas and identify learning issues at the microscopic representation level. Students exhibited an increased ability to offer comprehensive solutions and more targeted resolutions to the problems at hand. Additionally, their rationales, grounded in a more profound understanding of the microscopic level within the three representation levels of chemistry, were both more precise and scientifically robust.

Engagement in discussions through the online forum played a pivotal role in enhancing student collaboration (Amin et al., 2021). While interactions were previously limited to smaller groups, the online platform broadened this scope, allowing the entire class to participate. The integration of the Socratic method within the BPBL_S Module, which involves critical evaluation of students' responses, further refined their reasoning abilities. As a result, the forum sessions fostered deeper conversations, as reflected in the students' improved capacity to address complex questions, as shown in Figure 5.

Figure 5. Example excerpt from the online discussion forum at the microscopic representation level in Module 1

A3: What is the disadvantages of drinking lemon water while eating spicy food?

A1: Very acidic

Teacher: What is the characteristic of an acid? Can you explain more?

B2: Acid is corrosive, sour dan irritates to skin

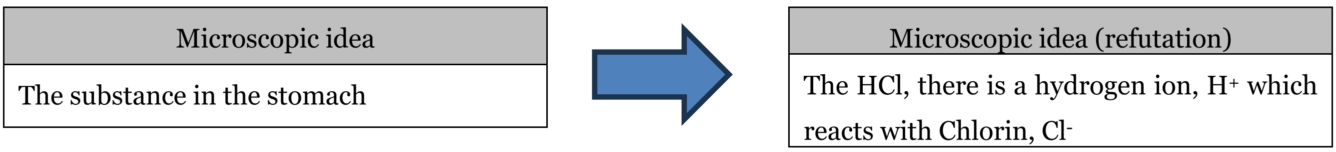
A1: This acid is indeed corrosive and sour, but not all acids are harmful to the skin because the acid in lemons is citric acid, which is edible. So, it's not dangerous, but since Razif has gastritis, it will worsen his condition and increase the erosion in his stomach. An acid is a chemical that contains hydrogen ions when it ionizes in water. The ionization of an acid producing hydrogen ions can also be viewed in terms of the strength of the acid. For example, citric acid is a weak acid, so its ionization is only partial. In the case of hydrochloric acid, which is a strong acid, the ionization is complete

The excerpts from the discussion forum shown in Figure 5 illustrate students' capacity to express thorough and scientifically accurate justifications regarding the characteristics of acids, their effect on skin, and the relationship between the degree of acid ionisation in water and its strength. This finding stands in contrast to the findings of Atikah et al. (2021)

and Ibrahim et al. (2022), who noted that students frequently encountered difficulties in justifying their responses to questions from teachers or peers. The robust justifications presented by the students suggest that the Socratic method is effective in refining their reasoning skills, especially at the microscopic representation level.

These results contrast with those observed by Nasir et al. (2017) and Omar et al. (2018), who highlighted students' difficulties in linking the extent of acid ionisation to its strength. A significant factor contributing to this challenge is students' struggles in forming mental models of acid ionisation. The microscopic representation level involves conceptualising abstract particles, requiring students to develop mental models to 'visualise' these particles (Chittleborough, 2014; Gkitzia et al., 2020). The BPBL_S Module effectively addresses this challenge by focusing on scaffolding, which aids in the development of students' mental models through iterative questioning from peers within and across groups, as well as from instructors. Furthermore, the online discussion forum plays a vital role in helping students refine their understanding at the microscopic level, especially through the revision of their responses in the FILA-refutation chart, as illustrated in Figure 6.

Figure 6. The change of microscopic idea in Module 1



In Figure 6, it was found that students could elaborate on microscopic ideas during the online forum discussion sessions. For example, students revised the microscopic idea from "the substance in the stomach" to "In HCl, there are hydrogen ions, H^+, which react with chlorine ions, Cl^-." This revised answer more accurately represents the microscopic representation level, encompassing atoms, molecules, and ions, according to the Particle Theory of Matter (Chittleborough, 2014; Johnstone, 1982). This can be evidenced by the interviews conducted with the group, as shown in the excerpt below.

Interviewer	:	After the forum discussion, did your group change the entry in the refutation column of the FILA chart from "the substance in the stomach" to "HCl contains hydrogen ions, H^+, which react with chlorine ions, Cl^-"? [TSB1B1M1S4]
B1	:	Yes, we changed "the substance in the stomach" to "HCl contains hydrogen ions that react with chlorine ions" because we found this answer more accurately represents the ions [TSB1M1J4]

The ability of students to elaborate on microscopic ideas allows them to identify more concrete and specific learning issues, thereby facilitating the information-gathering process to solve the given problems. Detailed microscopic ideas enable the generation of precise, focused, and comprehensive learning issues. This capability allows students to find solutions to problems with greater specificity and accuracy. This is evidenced by the student's ability to accurately address learning issues while also listing reference sources for these issues, as shown in Table 7.

Table 7. Example the answer to learning issues in Module 1

Question:	Does a gastric patient experience stomach erosion?
Answer:	Patients with gastric experience erosion of the stomach lining due to a high volume of hydrochloric acid, causing them to feel discomfort. Hydrochloric acid is a strong acid characterized by a high concentration of hydrogen ions. The ionization of hydrochloric acid can be represented as $HCl \rightarrow H^+ + Cl^-$. A strong acid is one that fully ionises in water, producing a high concentration of hydrogen ions. Reference: https://hellodoktor.com/penyakit-perut-gastrousus/gastrik/gastrik-apa-yang-berlaku-di-dalam-perut-anda/

The responses indicate that students successfully connected the scenario of stomach erosion to gastritis. Furthermore, they demonstrated an understanding of how hydrochloric acid, through its complete ionisation in water, leads to a high concentration of hydrogen ions. This suggests that students have effectively grasped the concept of strong acids, characterised by their degree of ionisation. Additionally, the use of the BPBL_S Module enabled students to bridge the microscopic representation level with the symbolic representation level, as shown by their accurate presentation of the chemical equation for the ionisation of hydrochloric acid in water: $HCl \rightarrow H^+ + Cl^-$.

This result differs from the research conducted by Pinto et al. (2023) and Nasir et al. (2017), which identified that students faced challenges in articulating the ionisation process of hydrochloric acid. Those studies highlighted misconceptions, such as the belief that hydrochloric acid would not react in water due to both being covalent compounds. However, despite water being a covalent compound, it is known as a universal solvent capable of ionising hydrochloric acid (Gao & Liu, 2022; Wang & Zhou, 2021).

Additionally, it was found that students could provide solutions to learning issues by proposing alternatives for resolving the given problems (Module 2: Acid rain problem). This is evidenced by their ability to suggest the best solutions for problems related to crops and fish farming affected by acid rain, as shown in Table 8.

Table 8. Example of the answer to learning issues in Module 2

Question:	What is the best solution to plant and fish farming?
Answer:	The best solution is to perform liming with an alkaline substance, such as slaked lime $Ca(OH)_2$. When the soil and farm water are acidic and contain hydrogen ions, the liming method using slaked lime, which contains hydroxide ions, can neutralize the acidic soil and farm water. The neutralization process with this liming method occurs as follows: $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$ Reference: http://zdocs.tips/doc/tindak-balas-peneutralan-8pg54x0gd06x

Table 8 shows students solving learning issues related to the impact of acid rain on crops and farmed fish. In groups, students provided detailed justifications for their learning issues. They successfully identified alternative solutions to tackle the issue, such as applying lime treatment with slaked lime ($Ca(OH)_2$). The microscopic concept highlighted in this context relates to the presence of hydrogen and hydroxide ions within a compound. In addition to offering accurate explanations at the microscopic representation level, students also cited the sources they consulted in resolving these learning challenges, as illustrated in Table 8. This indicates that students recognise the significance of reliable references, a principle strongly underscored in the BPBL_S Module.

Additionally, the results reveal that students were able to provide justifications at the microscopic level in response to questions posed by both instructors and peers. This capability suggests that the BPBL_S Module effectively enhances students' reasoning skills, leading to more accurate solutions, thereby addressing a common difficulty identified in previous research, such as those by Ibrahim et al. (2022) and Atikah et al. (2021). This improvement can be attributed to the incorporation of the Socratic method within the BPBL_S Module. Through this module, students are encouraged to ask questions based on prior responses, thereby refining their understanding through two key processes: (i) posing questions and (ii) providing justified answers (Suhadi et al., 2021).

During the presentation session, the teacher employed verification questions (Dalim et al., 2022) that challenged students' answers, such as, "If that is your answer, why not use a strong alkali like sodium hydroxide?" This thought-provoking inquiry exemplifies the Socratic method, which is designed to deepen students' comprehension (Suhadi et al., 2021). This type of question will challenge the listener to provide justifications (Suhadi et al., 2021). Students analysed the teacher's question and provided explanations, comparing the given examples: "Using sodium hydroxide is unsuitable for soil and fish ponds because it's a strong alkali, and it would kill all the fish."

From this feedback, it was clear that students recognised the impact of strong alkalis on living organisms. To obtain a detailed justification, the teacher asked, "What is special about calcium hydroxide?" A student from the same group, A1, responded, "Neutralising the soil doesn't mean reaching a pH of 7; it just needs to be suitable for planting."

Subsequently, student D4 asked, "What is the dangerous pH level for acid rain?" Student A2 replied, "Sulfuric acid and nitric acid are strong acids, so it would be around pH 3."

However, student D4 continued with a challenging question, stating his opinion: "Isn't sulfuric acid's pH 1?" From this question, student A2 clarified the pH comparison between sulfuric acid and acid rain: "As I understand it, sulfuric acid with a pH of 1 is like car battery acid and what we have in labs. Acid rain would be pH 3 or higher". This highlights how the questions posed, especially the challenging inputs from student D4, prompted students to provide thorough justifications, reflecting the core principles of the Socratic method employed in this module. At first, students believed that the pH of sulfuric acid in acid rain was as low as 1, comparable to the acidity of car battery acid. However, through a process of critical inquiry, they refined their understanding, recognising that the typical pH of acid rain is closer to 3. This iterative engagement of questioning and conceptual refinement underscores the Socratic method's efficacy in deepening students' comprehension of complex scientific ideas.

The findings overall indicate that the BPBL_S Module is a powerful tool for enhancing problem-solving abilities at the microscopic level in chemistry. By fostering active participation and encouraging rigorous argumentation, the module enables students to construct a deeper and more precise comprehension of abstract chemical concepts.

4.3 Problem-solving skills at symbolic levels in three representation levels of chemistry

The application of the BPBL_S Module has been instrumental in enhancing students' mastery of the symbolic representation level within the three representation levels of chemistry. By engaging in the problem-solving process embedded in the BPBL_S Module, students can elaborate on learning ideas at the symbolic representation level, and through presentations, their misconceptions can be identified and corrected. The integration of online discussion forums through the BPBL_S Module helps to elaborate on symbolic ideas by linking acid concepts to students' daily life situations. This is evidenced by the following excerpt from the online forum.

Figure 7. Example excerpt from online discussion forum at the symbolic representation level in Module 1

Teacher: What acids are present in lemon water? Does it cause stomach-ache?

B1: Citric acid can cause stomach-ache if consumed in excess

B1: In the mouth, neutrality is achieved because spicy foods are alkaline and lemon water is acidic. When an acid reacts with an alkali, it results in a neutralization reaction

A5: If spicy food can be neutralized in the mouth with lemon water, what about Razif's stomach, which suffers from gastritis? Is there any medication for this, or can he just drink Gaviscon?

B1: How can you just drink Gaviscon? Gaviscon is for people with heartburn and indigestion. In Razif's case, he shouldn't be taking Gaviscon because if we look at it again, his problem isn't related to heartburn. If it's gastritis, you can give an antacid that neutralizes the stomach pain. Antacids are bases but have alkaline properties.

A1: What my group wrote is correct. An example of an antacid is magnesium hydroxide, MgOH. From Mg(OH)2, it can ionize to produce hydroxide ions. Hydroxide ions are indeed present in alkalis. Just check the definition of alkalis in the textbook. An alkali is a chemical substance that ionizes in water to produce hydroxide ions, OH-. According to the Malaysian Health Portal, antacids will react with hydrochloric acid in the stomach, which functions to receive food, and increase the pH level to neutralize the acidity in the stomach, making it more neutral and relieving gastritis. The equation that can show neutralization occurs when hydrochloric acid reacts with magnesium hydroxide is: 2HCl + Mg (OH)2 --> MgCl2 + H2O.

It was observed that student A5 asked a clarification question to student B1 to obtain justification for their answer: "...Is there any medication for this, or can he just drink Gaviscon?" Student B1 not only answered A5's question but also suggested a relevant solution for Razif's stomach ache in the given problem scenario: "Gaviscon is for people with heartburn and indigestion. In Razif's case, he shouldn't be taking Gaviscon because if we look at it again, his problem isn't related to heartburn. If it's gastritis, you can give an antacid that neutralizes the stomach pain. Antacids are bases but have alkaline properties"

This demonstrates that the student has mastered the acid-base concept and can integrate this concept into daily life situations. The ability to relate abstract chemical concepts to students' daily activities is a key initiative in enhancing students' understanding of a chemical concept (Gilbert & Treagust, 2009; Johnstone, 2000). Furthermore, student A1 supported student B1 with a detailed justification and provided a reference example: "...The equation that demonstrates this neutralization is when hydrochloric acid reacts with magnesium hydroxide: $HCl + Mg(OH)_2 \rightarrow MgCl_2 + H_2O$."

From student A1's response, it is clear that they are trying to connect the microscopic representation level to the symbolic representation level by explaining the ions in $Mg(OH)_2$, namely Mg^{2+} and OH^- ions. The student also linked the presence of OH^- ions to the properties that influence the basicity and pH value of the compound. Additionally, student A1 attempted to construct a balanced chemical equation for the reaction between hydrochloric acid and magnesium chloride, though the equation was not balanced. After the online discussion session, there was a change in the symbolic ideas, as shown in Figure 8.

Figure 8. Changes in symbolic ideas during the online discussion forum in Module 1

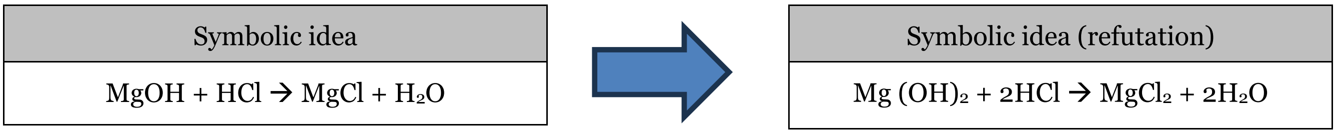


Figure 8 shows that initially, students provided an incomplete neutralisation equation in the discussion forum, such as "$MgOH + HCl \rightarrow MgCl + H_2O$". However, they later corrected it to the accurate equation, "$Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$," which represents the reaction between magnesium hydroxide and hydrochloric acid. This correction was largely influenced by the teacher's Socratic questioning, which encouraged students to critically evaluate their symbolic representations, "Is the chemical formula MgOH correct in the FILA-Refutation Chart?". Initially, student C1 confidently responded with "Yes." However, student A1, upon analysing the online discussion forum, realised that the chemical formula for magnesium hydroxide was incorrect and corrected it to $Mg(OH)_2$.

The BPBL_S Module's role in transitioning students from microscopic to symbolic levels of representation is further exemplified by the corrections made during classroom discussions. For instance, when student C3 asked "Can I ask, why is it carbonic acid and not bicarbonate?" In response, student A1 explained, "Carbonic acid forms when carbon dioxide dissolves in water while Bicarbonate forms when carbonic acid loses hydrogen". This interaction highlights the effectiveness of the Socratic method embedded within the BPBL_S Module in exposing and rectifying misconceptions.

Furthermore, during the presentation sessions in Module 2, the instructor identified a critical misconception concerning the formation of sulfuric acid in acid rain. A student mistakenly referred to "sulfuric acid gas," prompting the teacher to use Socratic questioning method to guide the student toward the correct explanation: "Not sulfuric acid gas, but rain droplets containing sulfuric acid." This interaction underscores the importance of teacher-facilitated the Socratic method in addressing and resolving misconceptions at the symbolic representation level.

In summary, students exhibited mastery of the symbolic representation level, equipping them to devise effective solutions for issues such as acid rain. This proficiency also allowed them to seamlessly integrate symbolic and microscopic representations, resulting in the accurate formulation of balanced chemical equations that elucidate the underlying chemical reactions. The BPBL_S Module was instrumental in cultivating this skill by encouraging active engagement and critical thinking through the integration of blended problem-based learning and the Socratic method.

Conclusions

The integration of the blended problem-based learning Socratic module (BPBL_S) has proven highly effective in enhancing students' problem-solving skills in three representation levels in chemistry. Drawing on Piaget's (1976) theory of the importance of prior knowledge, the module begins by assessing students' existing understanding through the FILA-refutation chart. This tool, combined with the Socratic method, is pivotal in identifying and correcting misconceptions, particularly in complex topics such as acids and bases. The module's approach aligns with Vygotsky's (1978) theory of knowledge construction through social interaction, further supported by Bruner's Constructivist Theory, which emphasises the role of social discourse in learning (Suhadi et al., 2021). The BPBL_S module integrates these pedagogical principles by encouraging dialogue among students through guided inquiry, thereby deepening their understanding and synthesis of new and existing knowledge. The Socratic method embedded within the module effectively stimulates critical thinking and detailed argumentation, crucial for mastering the three representation levels of chemistry concept. Furthermore, the blended learning modes of the module, which combine face-to-face and online interactions, significantly enhance collaborative learning. Online forums facilitate broad-based class discussions, addressing the limitations of traditional PBL that typically engages smaller groups. The modified FILA-refutation chart, featuring a dedicated 'refutation' column, further supports the collective refinement of ideas and responses, fostering a more nuanced understanding of chemical concepts. The module’s design is specifically tailored to overcome key barriers in traditional chemistry education. It provides structured guidance for integrating the three representation levels—macroscopic, microscopic, and symbolic—ensuring that students can seamlessly transition between these levels. Moreover, the module includes explicit strategies for teachers, such as exemplars for guiding student discussions and assessment rubrics tailored to BPBL activities. These resources aim to equip educators with practical tools to effectively implement the BPBL approach. In conclusion, the BPBL_S Module not only adheres to established educational theories but also serves as a potent tool for fostering active learning, critical thinking, and collaborative skills among students. It significantly improves their understanding and application of key chemistry concepts, aligning with the broader goals of reimagining STEM education to cultivate a future-ready workforce.

Research ethics

Author contributions

Ibrahim, M.M: conceptualisation, investigation/implementation, methodology, project administration, validation, visualization, writing—original draft preparation, writing—review and editing
MohdBadli, N.A.: conceptualisation, investigation/implementation, methodology
All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

This manuscript utilised artificial intelligence software; (i) ChatGPT and (ii) Grammarly to assist in checking the grammar.

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Institutional review board statement

This study received approval from the Ministry of Education, Malaysia, allowing the researchers to collect data in schools (see Appendix C). Furthermore, the researchers successfully attended the Human Research Ethics Workshop (see Appendix D), which is one of the requirements imposed by Universiti Pendidikan Sultan Idris, Malaysia on all students prior to conducting field data collection.

Informed consent statement

This study obtained written approval from the Ministry of Education Malaysia to utilize samples from schools, as detailed in Appendix C. Following this approval, the researcher approached the selected schools to secure consent from the school authorities to proceed with fieldwork, as outlined in the approval letter. Fieldwork commenced only after receiving the necessary permissions from the schools. Subsequently, each participant (teacher and students) was provided with a detailed explanation of the study and given the autonomy to decide whether to participate. Particular emphasis was placed on safeguarding the anonymity and confidentiality of the participants throughout the fieldwork to ensure their identities remained protected.

Data availability statement

The raw data on online forum, students' written response and part of interview transcripts were readily available in the manuscript as in Appendix E.

Acknowledgements

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Conflicts of interest

The authors declare no conflicts of interest.

Appendix A

Problem Scenario (Module 1)

You are a doctor at one of the rural health centers in the Manjung district. One day, a patient named Razif comes to see you for treatment related to his abdominal pain. The following is the dialogue between you and Razif.

Doctor	:	Good Morning, May I help you?
Razif	:	I have been experiencing abdominal pain that disrupts my daily activities almost every day this week. My stomach feels painful, especially before eating, and I often feel nauseous.
Doctor	:	Have you been experiencing any vomiting? [the doctor checks Razif's stomach]
Razif	:	Yes, but only once this week. I usually eat something sour, like 'asamboi,' to relieve the nausea.
Doctor	:	Oh, I see. May I ask if you have consumed any spicy food in the past few days?
Razif	:	Yes, spicy food is indeed my favorite
Doctor	:	How is your meal intake? Are you eating at the scheduled times?
Razif	:	I often eat at irregular times. I also frequently skip meals such as lunch, and sometimes I miss dinner and breakfast due to my work schedule constraints.
Doctor	:	May I know, what is your favorite drink?
Razif	:	I greatly enjoy drinking carbonated beverages like Coca-Cola, and when I eat spicy food, I prefer to drink lemon or lime water to relieve the spiciness

As a doctor, how would you explain to Ahmad about the gastric condition he is experiencing and how to manage it?

Problem Scenario (Module 2)

The majority of residents in Kampung Johar are farmers and livestock keepers engaged in small-scale agricultural and animal husbandry activities. However, in recent months, the village's crop yields have been increasingly declining. This is compounded by complaints from freshwater fish farmers, who report that many of their fish have died. Not only are agricultural and livestock areas affected, but the general health of the residents is also becoming increasingly concerning. Many residents have complained of persistent coughs and chest pains. Uncontrolled burning of forests for clearing farmland is cited as one possible cause of these problems. Additionally, the development of an industrial area near Kampung Johar may also be contributing to the issue. As an officer from the Department of Environment, you are tasked with monitoring Kampung Johar and finding the best solutions to address these problems.

Appendix B

PENGESAHAN TEMA

Saya telah menyemak tema-tema yang telah didapati daripada analisis tematik bagi kajian Pembangunan dan Keberkesanan Modul Pembelajaran Berasaskan Masalah Mod Campuran-Sokratik (PBMMC_S) Bagi Konsep Tiga Aras Perwakilan Kimia oleh Nurul Atikah Binti Mohd Badli dari Universiti Pendidikan Sultan Idris dan mendapati ianya bersesuaian dan bertepatan dengan contoh-contoh yang dikemukakan.

Sekian, terima kasih.

Tandatangan :

Nama : Dr Mohamad Termizi Borhan

Jawatan : Pensyarah Kanan

Cop Rasmi : Dr Mohamad Termizi Borhan
Jabatan Biologi
Fakulti Sains dan Matematik
UPSI

Appendix C

Universiti Pendidikan Sultan Idris
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Certificate of Participation

This certificate is proudly presented to

NURUL ATIKAH BINTI MOHD BADLI

950619065924

Who has successfully completed

HUMAN RESEARCH ETHICS ONLINE WORKSHOP 2021

14 SEPTEMBER 2021

PROFESSOR DR. RAHMATTULLAH KHAN
CHAIRPERSON
HUMAN RESEARCH ETHICS COMMITTEE
UNIVERSITI PENDIDIKAN SULTAN IDRIS

Appendix D

KEMENTERIAN PENDIDIKAN MALAYSIA
BAHAGIAN PERANCANGAN DAN PENYELIDIKAN DASAR PENDIDIKAN
ARAS 1-4, BLOK E8
KOMPLEKS KERAJAAN PARCEL E
PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN
62604 PUTRAJAYA

TEL : 0388846591
FAKS : 0388846579

Ruj. Kami : KPM.600-3/2/3-eras(11177)
Tarikh : 1 November 2021

NURUL ATIKAH BINTI MOHD BADLI
NO. KP : 950619065924

NO 145 JALAN SELUANG
FELDA SUNGAI RETANG 27000 JERANTUT
PAHANG

Tuan,

KELULUSAN BERSYARAT UNTUK MENJALANKAN KAJIAN :
PEMBANGUNAN MODUL PEMBELAJARAN BERASASKAN MASALAH MOD CAMPURAN- SOKRATIK (PBMMC_S) BAGI KONSEP TIGA ARAS PERWAKILAN KIMIA

Perkara di atas adalah dirujuk.

2. Sukacita dimaklumkan bahawa permohonan tuan untuk menjalankan kajian seperti di bawah telah diluluskan dengan syarat :

" KELULUSAN INI BERGANTUNG KEPADA PERTIMBANGAN PENGARAH BAHAGIAN PENDIDIKAN ISLAM, PENGARAH JPN DAN PERTIMBANGAN PENTADBIR SEKOLAH. "

3. Kelulusan adalah berdasarkan kepada kertas cadangan penyelidikan dan instrumen kajian yang dikemukakan oleh tuan kepada bahagian ini. Walau bagaimanapun kelulusan ini bergantung kepada kebenaran Jabatan Pendidikan Negeri dan Pengetua / Guru Besar yang berkenaan.

4. Surat kelulusan ini sah digunakan bermula dari **27 Oktober 2021** hingga **25 April 2022**

5. Tuan dikehendaki menyerahkan senaskhah laporan akhir kajian dalam bentuk *hardcopy* bersama salinan *softcopy* berformat pdf dalam CD kepada Bahagian ini.Tuan juga diingatkan supaya mendapat kebenaran terlebih dahulu daripada Bahagian ini sekiranya sebahagian atau sepenuhnya dapatan kajian tersebut hendak diterbitkan di mana-mana forum, seminar atau diumumkan kepada media massa.

Sekian untuk makluman dan tindakan tuan selanjutnya. Terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Saya yang menjalankan amanah,

Ketua Penolong Pengarah Kanan
Sektor Penyelidikan dan Penilaian Dasar
b.p. Pengarah
Bahagian Perancangan dan Penyelidikan Dasar Pendidikan
Kementerian Pendidikan Malaysia

salinan kepada:-

JABATAN PENDIDIKAN WILAYAH PERSEKUTUAN KUALA LUMPUR

* SURAT INI DIJANA OLEH KOMPUTER DAN TIADA TANDATANGAN DIPERLUKAN *

Appendix E

Figure 4. Example excerpt from online discussion forum at the macroscopic level for Module 2


Pelajar D5
yakin ke tumbuhan berkurangan sebab jerebu?? apa bukti dia?? jerebu effect ke fotosintesis dengan respirasi tumbuhan????
9 replies
Pelajar F5
apa relation jerebu dgn tumbuhan berkurangan?
Pelajar A2
iye dia effect kerana kekurangan cahaya matahari utk melakukan proses fotosintesis
Pelajar A2
sbb jerebu boleh menjadikan tanah berasid lalu tumbuhan x dapat nk hidup
Pelajar D5
Jerebu menjadikan tanah berasid?
Pelajar B2
Tanah berasid kerana berlaku hujan asid yang terhasil daripada gas-gas yang berbahaya daripada pembakaran hutan seperti sulfur dioksida, nitrogen oksida menjadi air hujan daripada asid sulfurik dan asid nitrik.
Pelajar D5
Jerebu pun salah satu fenomena pencemaran, jadi memang jerebu punca hujan asid?
Pelajar B2
Tidak, kami akan menggunakan hujan asid sebagai fenomena pencemaran berlaku sehingga menjadikan tanah berasid dan menyebabkan tumbuhan tidak dapat tumbuh dengan subur kerana hujan asid yang terjadi adalah titisan hujan asid sulfurik dan asid nitrik.
Pelajar D5
Apa yang terjadi kepada tanah dengan hujan asid yang jatuh ke bumi tu?
Pelajar B2
Berlaku pemendapan asid basah. Bila berlaku pemendapan asid basah dlm asid memang sedia maklum dah ada ion hidrogen yang mengganggu nutrien dalam tanah yang merendahkan nilai pH tanah sehingga menjadi lebih berasid.

Figure 5. Example excerpt from the online discussion forum at the microscopic representation level in Module 1

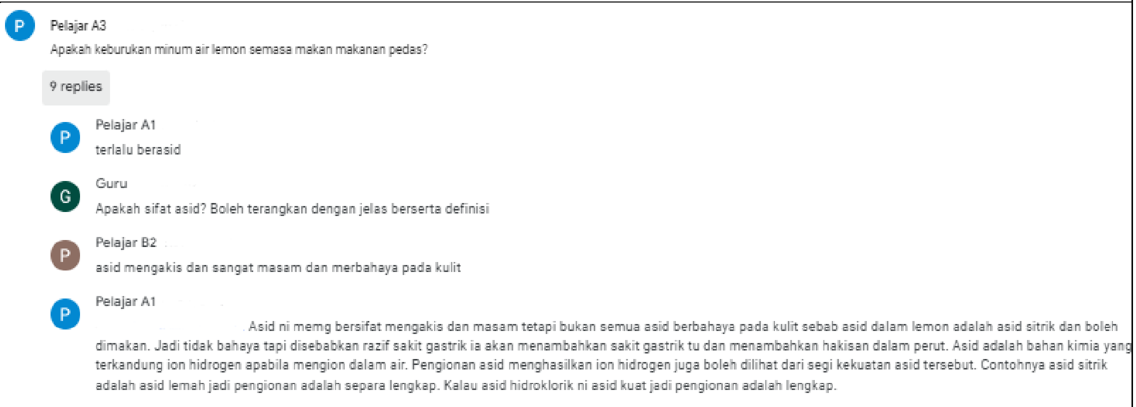
Pelajar A3
Apakah keburukan minum air lemon semasa makan makanan pedas?
9 replies
Pelajar A1
terlalu berasid
Guru
Apakah sifat asid? Boleh terangkan dengan jelas berserta definisi
Pelajar B2
asid mengakis dan sangat masam dan merbahaya pada kulit
Pelajar A1
Asid ni memg bersifat mengakis dan masam tetapi bukan semua asid berbahaya pada kulit sebab asid dalam lemon adalah asid sitrik dan boleh dimakan. Jadi tidak bahaya tapi disebabkan razif sakit gastrik ia akan menambahkan sakit gastrik tu dan menambahkan hakisan dalam perut. Asid adalah bahan kimia yang terkandung ion hidrogen apabila mengion dalam air. Pengionan asid menghasilkan ion hidrogen juga boleh dilihat dari segi kekuatan asid tersebut. Contohnya asid sitrik adalah asid lemah jadi pengionan adalah separa lengkap. Kalau asid hidroklorik ni asid kuat jadi pengionan adalah lengkap.

Table 7. Example the answer to learning issues in Module 1

PENYELESAIAN ISU PEMBELAJARAN

SOALAN	Adakah pesakit gastrik mengalami hakisan perut?
JAWAPAN	Pesakit gastrik akan mengalami hakisan pada dinding perut kerana terdapat isipadu asid hidroklorik yang tinggi sehingga menyebabkan rasa tidak selesa. Asid hidroklorik merupakan asid kuat yang mengandungi kepekatan ion hidrogen yang tinggi. Pengionan asid hidroklorik dapat dilihat daripada HCl -> H^+ + Cl-. Asid yang kuat adalah asid yang mengion lengkap di dalam air menghasilkan kepekatan ion hidrogen yang tinggi. Sumber: https://hellodoktor.com/penyakit-perut-gastrousus/gastrik/gastrik-apa-yang-berlaku-di-dalam-perut-anda/

Table 8. Example of the answer to learning issues in Module 2

Penyelesaian Isu Pembelajaran

1 response

S: Apakah penyelesaian yang terbaik untuk tanaman dan ikan ternakan?

J: Penyelesaian yang terbaik adalah dengan melakukan pengapuran dengan bahan alkali seperti contoh kapur mati seperti Ca(OH)2. Apabila tanah yang berasid dan air kolam ternakan berasid mengandungi ion hidrogen, kaedah pengapuran dengan menggunakan kapur mati mempunyai ion hidroksida dapat meneutralkan semula tanah berasid dan air kolam yang berasid. Dengan kaedah pengapuran ini proses peneutralan berlaku seperti ini
H2SO4 + Ca(OH)2 -> CaSO4 + H2O

Sumber: https://zdocs.tips/doc/tindak-balas-peneutralan-8pg54xogd06x

Figure 7. Example excerpt from online discussion forum at the symbolic representation level in Module 1

Guru
Apakah asid yang terdapat dengan air lemon? Adakah ia menyebabkan sakit perut?

Pelajar B
asid sitrik dan boleh sakit perut kalau terlebih

Pelajar B
Jadi neutral di dalam mulut sebab makanan pedas adalah beralkali dan air lemon adalah berasid, jadi bila asid bertindak balas dengan alkali akan jadi neutral.

Pelajar A5
Kalau makanan pedas boleh neutral dalam mulut dengan air lemon, macam mana pula dengan perut razif yang gastrik tu? Ada ubat ke? Ke boleh minum gaviscon je?

Pelajar B
Mana boleh minum gaviscon je. Gaviscon tu untuk orang yang sakit ulu hati dan ketidakhadaman, Kes razif ni bukan boleh minum gaviscon sebab kalau tengok semula masalah tiada kaitan dengan pedih ulu hati. Kalau gastrik ni boleh bagi ubat antasid yang meneutralkan sakit gastrik. Antasid ni adalah bes tapi bersifat alkali.

Pelajar A1
Betul apa yang kumpulan saya tulis tu. Contoh antasid adalah magnesium hidroksida, MgOH. Daripada Mg(OH)2 boleh diionkan untuk menghasilkan ion hidroksida. Ion hidroksida memang dah terdapat dalam alkali. Tengok aa maksud alkali dalam buku teks. Alkali ialah bahan kimia yang mengion di dalam air menghasilkan ion hidroksida, OH- . Klau tgok dlm portal kesihatan malaysia antasid akan bertindak balas dengan asid hidroklorik di dalam perut yang berfungsi untuk mencerna makanan akan meningkatkan nilai pH untuk meneutralkan tahap keasidan dalam perut untuk menjadi lebih neutral dan gastrik akan menjadi reda. Persamaan yang boleh menunjukkan peneutralan berlaku apabila asid hidroklorik bertindak balas ddengan magnesium hidroksida, 2HCl + Mg(OH)2 -> MgCl2 + H2O.

Interview transcript (macroscopic idea; Module 1)

Penemubual	:	Dalam ruangan idea makroskopik tersebut, pada mulanya kumpulan awak menulis “asid hidroklorik, enzim”. Tetapi selepas perbincangan dengan rakan-rakan kumpulan lain dan guru (refutation), anda menukar idea tersebut kepada “hakisan perut”. Boleh jelaskan **[TSB11M1S2]**
A1	:	Setelah berbincang dengan rakan-rakan dari kumpulan lain dan guru, kami dapati sakit perut yang dialami adalah disebabkan gastrik. Gastrik ini disebabkan berlakunya hakisan dalam perut, sebab asid. **[TSB1A1M1J2]**
Penemubual	:	Bahagian mana yang berlaku hakisan dalam perut? [**TSB1A1M1S3**]
A1	:	Hakisan yang berlaku adalah pada dinding perut bila dalam perut dah terlalu berasid. **[TSB1A1M1J3]**

Interview transcript (microscopic idea; Module 1)

Penemubual	:	Selepas forum perbincangan, dalam ruangan *refutation* di carta FILA tu adakah kumpulan awak menukar daripada “kandungan dalam perut” kepada “HCl yang terdapat ion hidrogen, H yang bertindak balas dengan ion klorin, Cl”? **[TSB1B1M1S4]**
B1	:	Ya, kami tukar “kandungan dalam perut” kepada “HCl yang terdapat ion hidrogen yang bertindak balas dengan ion klorin” kerana kami dapati jawapan tersebut lebih tepat dalam menggambarkan ion-ion [**TSB1M1J4**]

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