

E-Module problem-based learning on chemical equilibria to improve students' higher-order thinking skills: an analysis

Nur Syuhada Rusli, Nor Hasniza Ibrahim, Chuzairy Hanri, Johari Surif

School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, Skudai, Malaysia

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ABSTRACT

This study aimed to identify the specifications for developing a problem-based learning e-module for chemical equilibria to increase students' higher-order thinking skills (HOTS). A qualitative approach with a semi-structured interview involving eight participants from form six teachers in Penang was utilized. The interview results were analyzed using NVivo 12 software by dividing the transcripts into several codes based on a thematic analysis approach. Four broad themes emerged from the need analysis interviews: i) the importance of chemical equilibria; ii) problems in teaching and learning chemical equilibria; iii) teaching strategy; iv) desired improvement. The findings of this study showed that the topic of chemical equilibria in form six syllabus is an important topic for students to master. Still, it is the most challenging concept for both students and teachers. Findings of the interviews also found that teachers need an e-module integrated with problem-based learning due to the lack of teaching resources, the content of the syllabus, and the lack of students' thinking skills. Besides, teachers suggest variegating the content, strategies, and technology to develop the modules. These findings indicate that teachers are still unsatisfied with the existing teaching materials and strategies and, therefore require an e-module to meet their needs. All themes and codes of the findings are summarized using schematic diagrams. The results of this study are essential in designing and developing the e-module integrated with problem-based learning for the topic of chemical equilibria, which can be implemented and positively increase the HOTS level among form six students.

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Corresponding Author:

Nur Syuhada Rusli

School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia

Skudai 81310, Johor, Malaysia

Email: nsyuhadarusli87@gmail.com

1. INTRODUCTION

The traditional teacher-centered learning model must pave the way for student-centered learning to be efficient in the 21st century. To ensure students follow the learning process effectively and efficiently and achieve good results in this context, teachers must change the learning pattern by organizing and creating a learning environment using a variety of approaches [1]. The use of teaching and learning modules is one of the suitable strategies employed to achieve this goal. Previous research has shown that using modules in the teaching and learning process can benefit students of all abilities [2]. Additionally, modules can help students solve chemistry problems more effectively and connect newly learned theory to existing insight, which can assist them in learning [3].

The chemistry curriculum's emphasis on knowledge is complemented by instructions for students to develop better attitudes and skills. Students can boost their metacognition, creativity, teamwork, and

communication skills by learning chemistry [4]. One characteristic constantly desired in today's job market is the connection between students' higher-order thinking skills (HOTS) and their technological proficiency [5]. This demonstrates the importance of paying attention to HOTS aptitude in chemistry. In the 21st century, information and communications technology (ICT) and digital media play a significant role in chemistry education [6]. Correspondingly, the new *Kurikulum Standard Sekolah Menengah* content emphasizes computer-assisted chemical problem-solving skills to help students acquire HOTS and learn chemistry in a more enjoyable environment. Technology applications also significantly correlate with HOTS, especially in helping teachers integrate assessments based on it [7]. However, many teachers still practice teacher-centered learning, which makes students passive, only listening to teachers and memorizing information. Not being actively involved in the teaching and learning process makes it difficult for students to master HOTS [8].

2. PROBLEM STATEMENT

HOTS is the capacity for clear, rational thought and decision-making. The more advanced level of cognition, known as HOTS, is the level of analysis, synthesis, and evaluation [9]. HOTS is valued for its capacity for problem-solving, questioning, and critical and creative skills [10]. Students can solve chemistry problems and be prepared to compete in the global market through HOTS [11]. Chemistry students at the Malaysian Higher School Certificate (STPM) level must master HOTS to solve problems. For example, on concepts, to raise awareness of how important chemistry is to understand the natural world and the universe, think maturely, be knowledgeable, and be capable of communicating ideas using various methods. According to Hasan and Pardjono [12], HOTS is a fundamental skill given top priority when determining a graduate's employment eligibility. However, the study reveals that the level of HOTS among Malaysian students is still low and remains below the benchmark established by the Malaysian Ministry of Education [13].

HOTS can succeed when a person expands on interconnected information from stored memory to clarify intriguing circumstances or situations. However, students find it challenging to grasp the requirements of non-routine chemistry questions that apply concepts to reactions in the environment and involve much information, which prevents them from giving an accurate response. This result is also in line with the 2016-2020 STPM examination report, which found that most STPM candidates struggle to answer precisely HOTS questions. One observation in the STPM chemistry exam report is that in semester 1 of 2018, most candidates can correctly write the K_p representation. However, they find it difficult to apply and relate the knowledge from the previous topic (state of gaseous matter) to solve non-routine calculation problems involving chemical equilibria [14].

Chemical equilibria is one of the most important and difficult topics [15]. Studies show that when learning the concept of chemical equilibria, students struggle with the fundamentals of algebra, naming, and stoichiometry [16]. Besides, studies on students' comprehension of the topic of chemical equilibria conducted all over the world have also revealed several learning challenges. For example, according to Mensah and Morabe [17], the diagnostic report of the Mpumalanga Department of Education in South Africa reveals that students' performance on the topic of chemical equilibria is subpar, most of which indicates no achievement or complete failure. This demonstrates that students have serious trouble with chemical equilibria problems.

The 2018 STPM report also reveals that many candidates are still unable to solve calculations involving the concept of chemical equilibria and that other candidates are also unable to correctly interpret energy changes based on observing the idea [18]. The students must first evaluate and identify the information given in the calculation problem before connecting the knowledge of the concepts of mole and state of matter to arrive at the solution. The report demonstrates that students struggle with problem-solving. This proves that students' understanding of the HOTS for the topic of chemical equilibria is still underwhelming because they cannot apply what they have learned to the problems presented in the questions.

The teaching methods used by teachers are essential to provide opportunities for students to develop the ability to deal with problems and tasks cognitively to contribute to the development of the students' HOTS [19]. However, in current classroom learning, teachers still use the lecture method, which involves transferring material from the teacher to the students. This causes the lesson to become less meaningful and more focused on the student's ability to memorize information [20]. This situation causes teaching and learning activities to become less optimal. The study report of Szymkowiak *et al.* [21] showed that there are still groups of teachers that use traditional teaching approaches, especially groups with more than 20 years of teaching experience. This is because this group of experienced teachers feels it is difficult to adapt to online teaching changes. In addition, the report also states that many teachers deliver lessons based solely on lesson content and focus on teaching only. This causes the learning process to only occur on a fundamental basis. As a result, students cannot master the skills that should include HOTS.

The use of teaching materials or media, such as pictures, videos, animations, and others as mediators, is necessary to help students visualize a process or concept of chemistry so that it is easier to understand [22]. There is no denying that nowadays, most teachers have started integrating ICT in preparing

teaching materials, such as videos from YouTube links, to provide learning materials for the students to understand the chemistry process. However, the Malaysian Ministry of Education report shows that there are still teachers who have not and do not utilize ICT to implement the teaching and learning process. Therefore, the development of e-module in this study is expected to be used as an alternative teaching and learning material to help improve students' conceptual understanding and HOTS.

This study was carried out in response to the researcher's need to learn more about the importance of chemical equilibria, challenges with teaching and learning, teaching strategies, and suggestions. This is to improve and develop a problem-based learning e-module for chemical equilibria in improving students' HOTS. First, the needs analysis phase is conducted to determine whether the target group is experiencing any issues and to identify potential solutions [23]. Before the module is developed and evaluated in the following phase, Shanmugam *et al.* [24] stated that this requirement analysis phase is carried out to determine the module's requirements. Therefore, this study aims to identify the necessity of developing an e-Module Integrated with problem-based learning on chemical equilibria to enhance form six students' HOTS.

The research questions for the needs analysis phase are as: i) based on expert opinion, what is the importance of chemical equilibria?; ii) based on expert opinion, what are the challenges or problems encountered in teaching and learning chemical equilibria?; iii) based on expert opinion, what teaching strategies are practiced for chemical equilibria?; and iv) based on the opinion of experts, what are the desired improvement suggestions for the teaching and learning of chemical equilibria in improving students' HOTS?

3. RESEARCH METHOD

The semi-structured interview method is used in this qualitative study, where the researcher serves as a moderator and creates semi-structured questions to gather information from all participants. One benefit of using this semi-structured interviewing tool is that the researcher can choose the number of interview questions and add interview questions as needed during the interview. This is to elicit more information or in-depth answers to the research questions from some less obvious aspects [25]. This semi-structured interview method was also selected because it could deliver more thorough information while saving time and money [26]. The instrument developed by Wahid *et al.* [27] served as the basis for the semi-structured interview protocol that was used in this study. This protocol aims to gather verbal data from chemistry teachers regarding the importance of chemical equilibria, challenges associated with teaching and learning chemical equilibria, the teaching strategies, and suggestions for improving the important components and content that should be in the e-module to enhance students' HOTS.

3.1. Sample

There were eight teachers from various Penang form six colleges and centers participated in this study. Purposive sampling techniques are used to select informants. The researcher can then gather all the necessary relevant information using purposive sampling techniques, which are crucial [28]. Another benefit of this approach is that the study sample has the data the researcher needs and has a better understanding of the context or the actual state of the research problem [29]. The experts (teachers) interviewed were chosen based on several criteria: i) have at least five years of experience teaching form six chemistry; ii) teaching at a form six center or college in Penang; and iii) possess at least a bachelor's degree in chemistry or science.

These criteria guarantee that the chosen teacher or subject matter expert can offer the required information. This requirement is consistent with the definition by Yazdanmehr and Akbari [30] who defined experts as people with specialized knowledge and more than five years of professional experience. Teacher Ummi (G1), teacher Koh (G2), teacher Noor (G3), teacher Rus (G4), teacher Yazib (G5), teacher Has (G6), teacher Thana (G7), and Ms. Cai (G8) were chosen as the participants in this study. The interview informant selection criteria for the needs analysis phase are shown in Table 1. Due to data saturation at this level, additional informants are not required. Depending on the scope of the study, Creswell [31] claimed that the ideal number of qualitative samples falls between three and ten. Therefore, in this phase, eight teachers were selected using purposive sampling.

3.2. Pilot study

A pilot study was conducted to ensure that the interview instrument used for the study sample was appropriate [32]. According to Bogdan and Biklen [33], the validity and reliability used in this study entail expert validation of the interview protocol, pilot studies, and participant validation of interview data. Coe *et al.* [25] asserted that by carrying out a pilot study, the researcher can improve the instrument being tested or, at the very least, gain practical experience before carrying out the actual study. Pilot studies have been extended to qualitative research designs, though they have traditionally been associated with quantitative research designs to evaluate the validity and reliability of research instruments [34]. For the

validity of the semi-structured interview instrument, two instrument panel experts were appointed. Richey and Klien [35] claimed that expert evaluation and opinion can be used to determine the content validity of the interview protocol. Consequently, the experts chosen to evaluate and validate this interview instrument comprise university lecturers with in-depth knowledge and experience in creating instruments. Each expert must complete the instrument verification form after the evaluation. Some adjustments were made to the interview questions in response to the reviewers' comments and suggestions.

A pilot study was carried out to ensure the interview method could be applied in actual research after corrections were made in response to the evaluation panel's comments and recommendations. A teacher who has been teaching form six chemistry at one of the form six centers in Penang for more than 16 years is involved in this pilot study. The pilot study is conducted using informants chosen from the study location and the characteristics of the actual study sample. This is to ensure that the researcher can get interview practice in real situations and provide the usability and appropriateness of the interview questions. The semi-structured interview questions that had been prepared were the focus of the 30-minute pilot interview study session. According to the findings of the conducted interviews, the informant was able to comprehend the requirements of the questions and was knowledgeable in providing the required information. Besides that, the actual interview protocol can be executed over 30 to 40 minutes.

Table 1. Informant profile based on teaching place institution, gender, position grade, and selection criteria

Participant	Teaching place	Gender	Position grade	Criteria
G1	Form six centers	Female	DG44	Have a degree in science with a chemistry major, more than 12 years of experience examining and teaching form six chemistry coursework, one of the educators responsible for creating the STPM chemistry module for semesters 1 and 2 in the state of Penang, presenter of form six chemistry action research at the national level in 2021, served as the project's mentor since 2018
G2	Form six centers	Female	DG44	Graduated with a degree in science education (chemistry), has experience in teaching and reviewing form six chemistry coursework for over 12 years, once held the position as head of the form six chemistry unit for four years
G3	Form six centers	Female	DG48	Graduated with a degree with science option, DPLI in chemistry has a master's degree in science, have been a teacher and coursework reviewer for form six chemistry for more than 14 years, one of the educators who created STPM chemistry modules for the state of Penang's first and second semesters, possesses SPM chemistry paper marking experience and, as of 2018, has been a teacher supervising chemistry innovation projects, served as the form six chemistry unit's head since 2017
G4	Form six college	Female	DG48	Graduated with a degree with science option, more than six years of experience examining and teaching form six chemistry coursework, one of the educators responsible for creating the STPM chemistry module for the state of Penang's first semester, possess expertise in marking SPM chemistry papers, served as the form six chemistry unit's head since 2019
G5	Form six centers	Male	DG48	Graduated with a degree with science option and DPLI in chemistry, more than 14 years of experience teaching and reviewing form six chemistry coursework, one of the teachers who built STPM chemistry modules for the first and second semesters of the state of Penang, experience as SPM chemistry paper marker and has been a mentor teacher for a chemistry innovation project since 2018
G6	Form six centers	Female	DG52	Graduated with a degree with science option and DPLI in chemistry, more than 15 years of experience teaching and reviewing form six chemistry coursework, one of the teachers who built STPM chemistry modules for the first and second semesters of the state of Penang, experience as a marker for SPM chemistry papers and has been a teacher guiding chemistry innovation projects since 2018, held the position of head of form six chemistry unit since 2016
G7	Form six college	Male	DG52	Graduated with a degree in science and a master's with technology option, more than 21 years of experience teaching and reviewing form six chemistry coursework, one of the teachers who built STPM chemistry modules for the first and second semesters of the state of Penang, became a chemistry innovation project mentor since 2018, served as head of form six chemistry unit since 2015.
G8	Form six college	Female	DG44	Graduated with a degree in science option and a master's in psychology, experience in teaching and reviewing chemistry form six coursework for over eight years, one of the teachers who built STPM chemistry modules for the first and second semesters of the state of Penang, guide the chemistry innovation project since 2018.

3.3. Data analysis

In this study, expert interviews were conducted in a semi-structured manner to gather qualitative data. Several procedures were carried out for data analysis, including data preparation (transcripts of expert interview data), data organization, and data coding into specific codes. Recordings made during the implementation of the semi-structured interviews were used to gather the data. The informant was then given the complete interview transcript for content review and verification. Using the NVivo 12 program, each transcript written based on the interview recording was analyzed, divided into smaller codes, and coded

following the theme of the relevant research question. The steps of the theme analysis and data analysis processes using NVivo 12 in this study are in Figure 1. The coding is done based on the frequency of words and codes that appear in the data. Descriptive keywords chosen from the original words in the transcripts were used in the coding process. Finally, a tree structure with main themes is created based on the research questions and objectives.

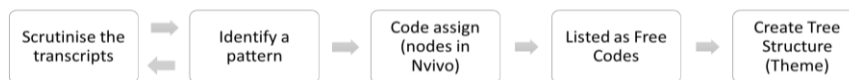


Figure 1. Data analysis process using Nvivo 12 [36]

4. RESULTS AND DISCUSSION

The objective analysis of this study resulted in the identification of four themes. The following are the themes: i) the importance of chemical equilibria; ii) the challenges in teaching and learning it; iii) the chemical equilibria teaching strategy; and iv) suggestions for improving the teaching and learning of chemical equilibria to encourage HOTS in form six students. Each theme is covered in the sections.

4.1. The importance of chemical equilibria

Chemical equilibria are one of the subjects covered in first semester of the form six chemistry curriculum. There are eight learning objectives for students to master in this topic, which is listed as the first topic for the subject of equilibria: i) describe reversible reactions and dynamic equilibria in terms of reactions forward and backward responses; ii) state the laws of mass action based on stoichiometric equations; iii) derive expressions for the equilibrium constant in terms of concentration, K_c , and partial pressure, K_p , for homogeneous and heterogeneous systems; iv) calculate the value of the equilibrium constant in terms of concentration or partial pressure based on the given data; v) calculate the quantities that exist at equilibrium based on the given data; vi) apply the concept of dynamic chemical equilibria to explain how the concentration of stratospheric ozone is affected by the photodissociation of NO_2 , O_2 , and O_3 to form radicals oxygen reactive; vii) state Le Chatelier's principle and use it to discuss the effect of a catalyst, change in concentration, pressure, or temperature on a system in equilibrium; and viii) explain the effect of temperature on the equilibrium constant.

Reversible reactions and dynamic equilibria are introduced in the first section of this chapter. The following lesson continues with an explanation of the laws of mass action before submitting and calculating the equilibrium constant, applying the idea of chemical equilibria and discussing the variables that affect it as well as explaining how temperature changes affect the equilibrium constant. As a result of the conducted interviews, two codes—the fundamental idea and application, have been developed to explain the importance of chemical equilibria. In the schematic diagram of Figure 2, the themes and codes that emerged from examining the interview data are summarized.

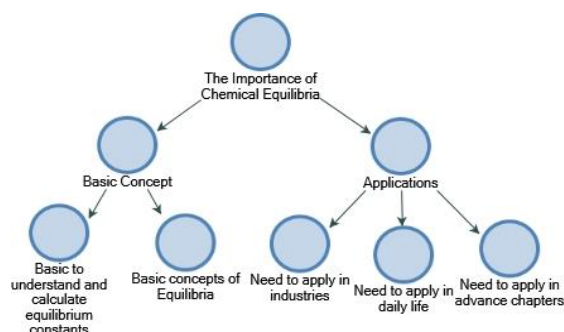


Figure 2. Importance of chemical equilibria

All eight participants affirmed that chemical equilibria are a core concept that students need to understand to learn the remaining subjects. Chemical equilibria are the main aspect to grasp in explaining most of the chemical processes and reactions around us. This is because chemistry involves the study of substances that exist in nature and the changes that result from interactions between those substances. In addition, it regularly overlaps with most other fields of science. As a result, students risk finding it

challenging to grasp other closely related topics, such as acids and bases, solubility and solubility products, salt hydrolysis, and redox reactions.

“If the students are unable to grasp the concept of chemical equilibria, they will have a hard time understanding solubility.” (TB-G1-24/01/2022:95-96)

The form six chemistry curriculum’s content also reveals that chemical equilibria are brought up again in later chapters. G4 added that chemical equilibria are the foundation of a reversible system and is relevant to daily life. According to G1 and G7, understanding the idea of chemical equilibria is necessary for the industry because it can help the sector increase output while lowering the risk of losses. G2 also concurred on the subject, stating that students will be able to explain how to solve pollution by using their knowledge of chemical equilibria to identify the causes.

It was determined from the analysis that the concept of chemical equilibria is something that students need to grasp before learning other relevant and significant topics to explain the majority of phenomena that occur in daily life and industry. This concept is widely used in industry, especially in the production of ammonia, sulfuric acid, and other essential ingredients for the production of a vast array of other products. In addition, G1 stated that understanding the concept of chemical equilibria can help the industry increase productivity and reduce waste. G7 clarified:

“There is indeed a need for that. Especially if we are talking about working in the chemical manufacturing industry specifically. Most of the students who are taking the Science stream would venture into manufacturing. So, understanding chemical equilibria is vital for them to be able to do continuous improvement (CI).” (TB-G7-13/07/2022:36-41)

4.2. Problems in teaching and learning chemical equilibria

In the process of teaching and learning chemistry, teachers and students encounter a variety of difficulties. According to the analysis of the interview data, various viewpoints have been expressed regarding the challenges faced when teaching and learning chemistry. Therefore, the analysis developed eight codes under this theme: too many calculations, weak basic knowledge, abstract concepts, student attitudes, and technical issues. Figure 3 provides a summary of the themes and codes.

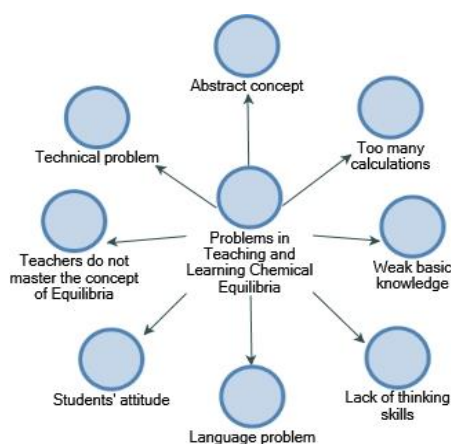


Figure 3. Problems in teaching and learning chemical equilibria

According to the analysis, the topic of chemical equilibria contains abstract concepts that fall into the problems identified in the teaching and learning process. This study discovered that because the subject of chemical equilibria contains so many intricate and abstract ideas, it is difficult for teachers and students to teach and learn it. This result is in line with Tsoi *et al.* observation [37] that students struggle with the many abstract concepts in the chemistry curriculum. G4 admitted that it was difficult to explain chemical equilibria to students because it was abstract. G2 believed it is challenging for students to comprehend, picture dynamic equilibria, and recognize the reverse reaction process. G1, G7, and G8 all agreed with this statement, stating that equilibria encompass some intricate and esoteric ideas. According to Jusniar *et al.* [15], most of the concepts in chemical equilibria are abstract, and the use of representations makes it challenging for students to comprehend this subject. The study found that 56.7% of teachers who agreed that abstract concepts cause students’ struggles with the equilibria topic agree with this finding [16].

The code contains far too many calculations. G1 claimed that because one of the essay questions on the exam's chemical equilibria topic requires many calculations and is difficult to understand, students opt not to answer it. She continued by saying that students commonly confuse the initial value with the dissociation value and cannot determine the correct value to calculate the Equilibrium Constant. This is supported by G2, who notes that students require a lot of time to finish and comprehend the calculations involved in this topic. Additionally, G4 and G8 noted that students found it challenging to understand many calculations, particularly those that involved calculating the equilibrium constants, K_c and K_p . Because of this, students struggle by not getting enough practice and must move on to the next subject before they can fully grasp the topic of chemical equilibria.

The study's results also demonstrate that students struggle with a lack of comprehension of basic concepts. The basic concepts covered include writing and balancing chemical equations, calculating moles, pressure, and concentration of substances, reaction rates, how temperature affects reaction kinetics, and how catalysts work. Most informants concur that learning the subject of chemical equilibria can be challenging for students who do not understand the fundamentals or have a weak foundation in chemistry, especially when it comes to mastering the calculation part. This result is in line with the study by Shing and Brod [38], which found that students' mastery of basic concepts is a key factor in facilitating or limiting their understanding of related concepts. In addition, Ganasen and Shamuganathan [39] found that before studying the idea of chemical equilibria, students should have a basic knowledge of reaction rates. G8 explained this situation:

“Calculations for chemical equilibria, especially those involving K_c and K_p they are unable to recognize those. They cannot even differentiate, let alone recognize K_c .” (TB-G8-13/07/2022:51-53)

The student's inability to think critically is a further barrier to their mastery of the topic of chemical equilibria. All of the informants agree that throughout the learning process, students lack knowledge and infrequently pose insightful questions. Most students memorize information instead of applying it, preventing them from appropriately responding to various situations. G1 clarified that many students struggle to explain how the concepts they have learned are applied and, therefore, cannot appropriately respond to HOTS questions. G3 also agreed on this point, stating that students must have analytical skills and be able to relate existing knowledge to concepts learned because understanding the topic requires more than just comprehension. Students find it challenging to explain a concept using their sentences and words and master HOTS when they are taught to memorize notes or calculation work steps. According to Sirhan [40], students have trouble learning chemistry because they believe it requires them to memorize formulas and symbols. This result demonstrates that one of the challenges students face in learning chemical equilibria is a lack of critical thinking abilities.

Some informants noted that diverse and underprivileged student backgrounds contributed to language comprehension issues, which are codes that appear in the theme of difficulties in teaching and learning chemistry. Most students received average to subpar results on the Malaysian Certificate of Education (SPM) exam. Informant G4 asserted that this made it difficult for them to comprehend the teaching presentation in Malay and English. G4 added that even the best students have trouble using precise language to explain ideas. G8 also brought up those students had trouble fully comprehending the concepts because they had difficulty understanding the sentences used in the notes and questions.

The analysis also revealed that one of the issues with chemistry teaching and learning is student attitudes. Students' unwillingness to ask questions, lack of focus, lack of cooperation during the teaching and learning process, and inability to complete assigned tasks are just a few of the attitude issues mentioned.

“We could easily see through asking questions to the students, through their feedback and the way they answer; the face-to-face indicators in their responses and understanding. It was subpar at best.” (TB-G2 05/07/2022:225-228)

G6 also mentioned that some students were not fully present and engaged in the teaching and learning process. These students are typically weaker and have trouble understanding this subject, particularly the calculation portion. G2 also mentioned that during class, students frequently ask the teacher to answer their questions rather than posing thoughtful ones.

One of the issues with teaching and learning chemical equilibria is that many teachers do not understand the concept of equilibria well. Informant G4 admitted that there were difficulties comprehending the topic of chemical equilibria, and much time was needed to review it, which made it difficult to explain the idea clearly. This was further supported by G7, who claimed that the topic of equilibria is particularly difficult for novice teachers. Even with the teaching experience, revisions and preparations still need to be thoroughly done for this lesson.

The results also indicate that one of the difficulties in teaching and learning chemistry is due to technical issues. Time constraints make up one of the technical issues. The syllabus cannot be completed in time. As a result, teachers cannot concentrate on a single topic for long periods. Chemical equilibria are one of the six topics covered in semester one's form six chemistry curriculum, so it is taught at the end of the semester. According to G3, she rushed through the curriculum and taught speedily because the chemical equilibria topic was at the end. Due to a lack of time to ask the teacher questions, students could not comprehend the subject matter thoroughly. Additionally, G4 stated that the topic of chemical equilibria requires an in-depth explanation to ensure that students can understand it well. The lesson was unable to be delivered in its entirety due to time constraints and the measure's length, making it difficult for the students to follow the topic. This result is consistent with the findings from Ballen and Ospina [16], whose research suggests that the main reason students have trouble mastering the topic of equilibria is that it is very broad and has many subtopics. Citing G2's remarks:

"I feel sorry for them. There are a lot of things they have yet to master, while STPM is just around the corner... so everyone is rushing to finish the syllabus." (TB-G2-24/01/2022:190-192)

In most cases, the informant also confirmed that using animation and video in chemical equilibria can aid students in visualizing abstract ideas. However, teachers cannot download videos from websites like YouTube due to technical issues, such as the lack of internet connection in the classroom. G2 claimed that it must be done via an internet-connected mobile device to show videos or animations to his students. G1 also expressed acknowledgment of this issue;

"Wi-Fi is available at school, but we cannot access it in the class. So, I usually use my personal internet connection. For example, if I want to show them some YouTube videos, I would do it through my internet connection in the class." (TB-G1-24/01/2022:146-149)

Some informants listed the lack of teaching aids as one of their issues under this technical problem code. G5 and G6 acknowledged that one of the biggest challenges they face in explaining the idea of chemical equilibria is the lack of teaching resources. Additionally, G8 stated that the ministry's software used to implement *Pengajaran dan Pembelajaran Sains dan Matematik Dalam Bahasa Inggeris* as a learning medium is no longer appropriate.

4.3. Chemical equilibria teaching strategies

It is said that conceptual difficulty does not just appear out of the blue. Instead, it is propelled by the teaching method. Doymus [41] asserted that to make the subject of Chemical Equilibria easier for students to understand, the approach or methods of teaching it need to be changed. Therefore, many teaching methods have been presented to aid in learning this subject. Figure 4 summarizes the code for the chemical equilibria teaching strategies.

According to the study's findings, most informants concurred that they use many exercises to teach the subject of chemical equilibria because the majority of its sections involve calculations. Additionally, most informants consistently mentioned the number of calculations on this subject as their biggest challenge throughout the interview session. As G1 previously stated, a variety of practice questions was used instead of strictly concentrating on determining the equilibrium constant's value. To help students become accustomed to questions in the form of HOTS, she frequently uses past exam questions as well as problem-solving and practice questions. G2, G4, and G8 all agreed that students need more time to practice answering calculation questions. They further stated that they would ensure each practice question given to the students was discussed for them to comprehend the solution method fully. They also ensured that every exercise not discussed was provided with an answer as a reference for the students.

Additionally, some informants mentioned using the instrument on chemical equilibrium (ICE) table to teach this subject, particularly for inquiries concerning the equilibrium constant. Using this method, students will find it simpler to choose the value that should be input into the equilibrium constant calculation.

G1: *"For the calculations involving K_c and K_p , I am using the ICE (initial, change, and equilibrium) table. The table makes it easier for students to apply the right values in expressing K_c and K_p ."* (TB-G124/01/2022:186-189)

Furthermore, G3 added that he always provides step-by-step solutions when teaching the calculation portion of chemical equilibria. The fact that students have guidance makes it simpler for them to understand how to solve problems fully.

The study's findings also demonstrate that all respondents share the same opinion about the value of using multimedia to teach chemical equilibria. Specifically for Le Chatelier's principle, they claimed that videos and animations could aid students in visualizing abstract chemical equilibria concepts. G1 emphasized the benefit of using multimedia to demonstrate Le Chatelier's principle because it allows students to understand more clearly what happens to equilibrium when a system is disturbed. Students understand the concept better when they can see the animation of a material's change or movement. This claim is supported by G2, who notes that students become more engaged and eager to learn after they were shown the application video and emphasized the significance of the chemical equilibria concept. It was asserted that students are more receptive to conversations and inquiries about the application videos being shown.

“For me, in terms of application, the use of multimedia applications is indeed helpful because it could attract students in learning more about this topic.” (TB-G2-24/01/2022:250-252)

G5, G7, and G8 mentioned the self-learning module usage code. For the chemical equilibria lesson, all informants used a teaching module they had created themselves. G7 claimed that he felt more at ease using self-prepared modules because the entire content was set up by the syllabus and the requirements of the students. The same was stated by G8, who uses a self-prepared teaching module that includes notes and varying exercises.

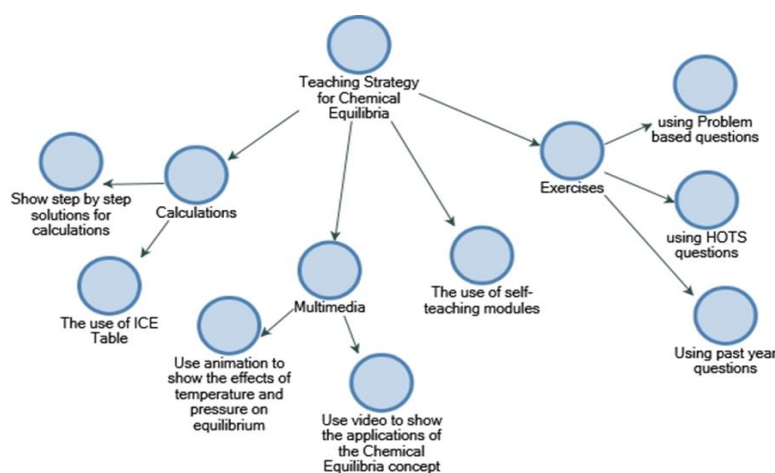


Figure 4. Chemical equilibria teaching strategies

4.4. Desired improvement for teaching and learning of chemical equilibria

The analysis of the desired improvement suggestions for teaching and learning the topic of chemical equilibria in improving students' HOTS achievement resulted in the formation of two main codes. Two main codes are the problem-based learning approach and technology. The developed themes and codes were summarized using a schematic diagram such as Figure 5.

Nearly all the informants agreed that students need to be exposed to real problems to familiarize themselves with HOTS questions and as an alternative form of learning under the problem-based learning approach code. G1 and G7 emphasized that to stimulate students' minds and give them the ability to connect the ideas they have learned to actual circumstances; they must be exposed to questions involving issues and procedures in the industry as well as the environment. According to G2 and G6, the problem-based learning approach is advantageous for students because it enables them to become familiar with real problems while also aiding them in responding to STPM questions, primarily HOTS questions. Furthermore, according to G2, six students can develop their potential to think outside the box through problem-based learning tasks.

The informants generally agreed that the problem-based learning approach is ideal for this topic because it allows for active student participation through group projects. G1, G4, and G6 claimed that students could improve their communication skills by participating in group activities and subconsciously encouraging others to ask questions. This is because students feel more at ease asking questions of their peers than teachers. Wahid *et al.* [27] asserted that teachers can assess their students' conceptual understanding and mastery by having them ask questions. G1 and G7 also stressed the need for teachers to serve as facilitators to oversee and direct each group's discussion. The words of G2 serve to highlight this point:

G2: “Due to them being from six students they must develop self-confidence and the ability to work with others so group activities like this are very suitable as when they are with friends, they tend to be less shy, and that would encourage them to ask questions.” (TB-G2-24/01/2022:294-298)

G2 also suggested a method of teaching that can stimulate students' curiosity. According to G2, students will be eager to follow the lesson material and can be motivated to participate fully in all of the activities. Therefore, the problem-based learning approach is recommended as a development to instruct and learn the subject of chemical equilibria. The technology code also has a learning approach code that can stimulate students' curiosity. G2 and G8 explained that using a video to introduce the idea of chemical equilibria could spark interest and make the students curious about the content of the lesson they are learning. This is necessary to keep students focused and interested.

Moreover, all informants concurred those illustrations of reaction processes, the use of concepts in real-world situations, and Le Chatelier's principle can aid students in visualizing and comprehending the difficult and abstract concept of chemical equilibria. Students need assistance with visualization to learn abstract phenomena that are difficult to observe in chemistry classes [42]. G1, G4, and G8 all agreed that using animation to explain Le Chatelier's principle, in particular, could help students understand it better. This is because they can see how increased gas pressure, concentration, and temperature changes can disturb or alter systems in equilibrium. G2 suggested using diagrams to show how to use the ICE Table and the steps involved in working through some real-world calculation problems. This is crucial to help students remember references and employ the right way to solve problems.

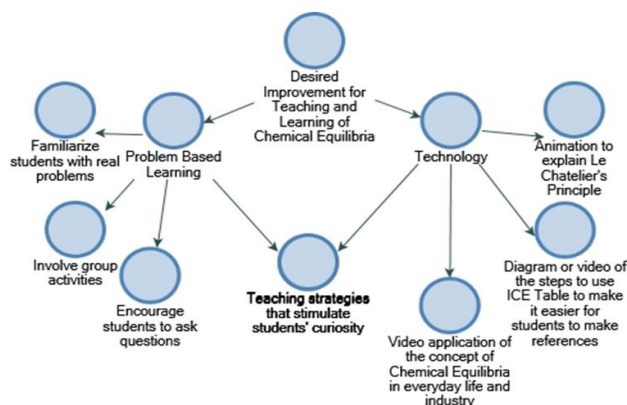


Figure 5. Desired improvements for teaching and learning chemical equilibria

5. CONCLUSION

According to the eight informants (experts), students must understand chemical equilibria because it facilitates the integration of knowledge across various chemistry topics. Most industrial processes and daily life have many applications to this subject. Students' inability to comprehend abstract and difficult concepts in chemical equilibria is their main barrier. Therefore, all teachers should be aware of the learning strategies regarding applying HOTS in the teaching of chemical equilibria and should put them into practice. Teachers should also strive to employ various teaching methods and be open to new ideas.

This study is key for assisting educators and researchers in narrowing their attention to particular topics to prevent overt instruction that hinders the acquisition of crucial knowledge. Researchers can create effective interventions using this methodology. Based on the four themes identified, it is necessary to develop an alternative teaching module to aid in the teaching and learning of chemistry and the application of HOTS for the topic of chemical equilibria for both teachers and students. The study's findings indicate that everyone interviewed believes that using technology to study chemical equilibria is both relevant and essential in the current digital era. Additional research is also suggested by emphasizing the effects of digital literacy skills on form six students and the topic of chemical equilibria.

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BIOGRAPHIES OF AUTHORS






Nur Syuhada Rusli    is a postgraduate Ph.D. student of chemistry education at Universiti Teknologi Malaysia. Her passion for science education has been from the foundation where she also obtained a Bachelor of Education in chemistry from the Universiti Teknologi Malaysia and a master's degree in science education from Universiti Kebangsaan Malaysia. Nur Syuhada has been a chemistry teacher for twelve years and has an interest in chemistry pedagogy and STEM education. She can be contacted at email: nur87@graduate.utm.my.






Nor Hasniza Ibrahim    received her bachelor's in biomedical sciences from Universiti Putra Malaysia, master degree, and doctor of philosophy in Chemistry Education from Universiti Teknologi Malaysia. Her research interest is regarding science education, chemistry education, and STEM education. She now works as an associate professor in the Department of Educational Science, Mathematics, and Multimedia Creative, Faculty of Science Social and Humanities, Universiti Teknologi Malaysia. She is also currently actively involved in research and programs related to STEM education and indigenous people. She can be contacted at email: p-norhaniza@utm.my.



Chuzairy Hanri    is a senior lecturer at Universiti Teknologi Malaysian. His expertise in chemistry education includes scientific argumentation, scientific creativity, and STEM education. He can be contacted at email: chuzairy@utm.my.



Johari Surif    received his bachelor's in environmental sciences from Universiti Kebangsaan Malaysia, a master degree, and a doctor of philosophy in chemistry education from Universiti Teknologi Malaysia. His research interest is regarding science education, chemistry education, and STEM education. He now works as an associate professor in the Department of Educ Science, Mathematics, and Multimedia Creative, Faculty of Science Social and Humanities, Universiti Teknologi Malaysia. He is also currently actively involved in research and programs related to STEM education, community, and many more. He can be contacted at email: johari_surif@utm.my.