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Addressing Chemical Misconceptions Based on Multi-Representation with the PIMOTS Multimedia-Assisted Inquiry Learning Model

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ABSTRACT

The problem and the aim of the research. Chemistry, as a natural science, is closely connected to life at both micro and macro levels. One key concept is the reaction rate, which describes how quickly reactants change into products over time. Students often misunderstand this concept, for instance by focusing only on the amount of reactant and overlooking time as a crucial factor. Left unaddressed, such misconceptions hinder deeper understanding. To tackle this, a learning approach that combines multiple representations, inquiry, and multimedia technology is needed, helping students move beyond memorizing formulas toward meaningful interpretation and application. *The aim of this study* is to test the effectiveness of the PIMOTS multimedia-assisted inquiry learning model, which integrates multiple chemical representations, in preventing and reducing students' misconceptions about reaction rates.

Study participants and methods. The participants of this study were 68 eleventh-grade students from two randomly selected classes (XI-A and XI-B) at a senior high school in Surabaya, Indonesia. These students were chosen because they had not previously studied the topic of reaction rates formally in class, so their initial conceptions could be identified more clearly. The sample represented typical science program students at the senior high school level, providing a relevant context for examining common misconceptions and testing the effectiveness of the PIMOTS multimedia-assisted inquiry learning model.

Results. The implementation of learning achieved an average score of 89% in class XI-A and 91% in class XI-B, categorized as outstanding. Student activities reached 93% in class XI-A and 92% in class XI-B, indicating that the learning process was highly student-centered. Questionnaire responses were also very positive, with interest, ease of use, and learning outcomes scoring 86%, 91%, and 88% in class XI-A, and 83%, 86%, and 82% in class XI-B. Furthermore, the proportion of students with scientific conceptions increased to 75% in class XI-A and 78% in class XI-B, while misconceptions decreased to 6% and 4%, respectively. The Wilcoxon signed-rank test confirmed that these conceptual changes were statistically significant ($p < 0.05$), demonstrating that the PIMOTS multimedia-assisted inquiry model effectively reduced misconceptions and enhanced students' understanding of reaction rates.

Conclusion. This study has tested the effectiveness of preventing misconceptions about reaction rates using a multi-representation approach with a multimedia-assisted inquiry learning model, PIMOTS, which produced positive outcomes. Furthermore, this study demonstrates the novelty of simultaneously integrating the inquiry model with a multi-representation approach and PIMOTS-based media to systematically prevent misconceptions, which are rarely explored in previous research on reaction rates. Furthermore, this approach has a complex function, serving as a visual aid developed as a conceptual strategy to enhance students' in-depth understanding of chemistry.

KEYWORDS

multi-representation, misconception, multimedia, reaction rate, four-tier

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INTRODUCTION

International organizations such as UNESCO, the Council of Europe, and the Union of International Associations (UIA) emphasize the importance of improving the quality of science education as part of global efforts to achieve sustainable development and 21st-century competencies [1]. These initiatives highlight the need for learning models that foster critical thinking, problem-solving, and deep conceptual understanding across nations, including in chemistry education. Chemistry is a science that discusses matter in terms of its properties, the changes it undergoes, and the energy involved in these changes [2]. There are three levels of representation in chemistry: macroscopic, submicroscopic, and symbolic [3]. The macroscopic aspect explains phenomena that occur and can be directly observed in everyday life, such as density and solubility. The submicroscopic aspect describes abstract chemical characteristics that explain macroscopic phenomena [4]. This aspect consists of representations of matter based on its particulate properties, while the symbolic aspect includes images, symbols, and mathematical relationships in chemical equations. These three representations are interrelated and help students understand abstract chemical material [5].

Misconception, according to Malaterre (2023), is a lack of understanding in connecting one concept with another, especially between a new idea and an old concept already embedded in students' minds [6]. Such misconceptions must be addressed to prevent recurrence in subsequent materials [7]. Research using the Focus Group Discussion (FGD) method has found misconceptions in reaction rate material, particularly in the sub-concept of how catalysts influence reaction rates [8]. The presence of diverse misconceptions in reaction rate concepts indicates that these problems need immediate intervention. Many misconceptions arise from rote, meaningless learning and must be addressed by involving the three chemical representations. Delivering learning materials with multiple representations can improve students' interconnection skills, training them to connect information across levels of representation and to understand concepts meaningfully [9]. When the three representations are clearly conveyed and applied in everyday contexts, students gain a more complete understanding [10]. One way to achieve this is by modelling submicroscopic phenomena as a bridge for students to relate macroscopic observations to symbolic equations [11]. Prior studies have shown that multi-representation-based learning positively influences student understanding.

Guided inquiry models combined with multi-representation approaches have been proven effective in enhancing understanding [12]. In addition to raising critical thinking skills from low to high levels, multi-representation learning also improves mastery of concepts. Learning media presented through multi-representation strongly supports conceptual understanding because it incorporates macroscopic, submicroscopic, and symbolic perspectives [13]. Improved conceptual understanding reduces the likelihood of misconceptions, since weak conceptual grounding often leads to misunderstandings [14].

Effective learning can be achieved by designing learning tools such as teaching modules, worksheets, test instruments, and multimedia [15]. Well-designed chemistry learning tools on topics like reaction rates can serve as inquiry-based resources to prevent misconceptions, supported by multimedia platforms such as PIMOTS (Preventing Misconceptions Websites). PIMOTS can also inspire similar developments for other chemistry topics. However, many classrooms still rely on teacher-centred instruction, which leaves students less engaged and focused mainly on memorisation [16]. This highlights the need for learning models that prioritise student activity and problem-solving, such as inquiry models.

Chemical multi-representation involves studying chemistry simultaneously through macroscopic, submicroscopic, and symbolic levels [17]. Macroscopic representations explain observable phenomena in daily life and laboratories [18]. Submicroscopic representations describe matter at the particulate level, while symbolic representations use images, symbols, and equations [19]. These three complement one another: macroscopic phenomena provide concrete examples, submicroscopic models help students visualise underlying processes, and symbolic forms represent equations or quantitative relationships [20]. Unfortunately, school chemistry often emphasises only macroscopic and metaphorical levels, leaving submicroscopic explanations underdeveloped and students' understanding incomplete [21].

Therefore, the design of learning tools must align with the syntax of inquiry learning: (1) presenting relevant problems, (2) formulating hypotheses, (3) designing experiments, (4) collecting and analysing data, and (5) concluding [22]. Figure 1 illustrates the initial view of PIMOTS.

Figure 1 PIMOTS home page

THEORETICAL BACKGROUND

1. Misconception

Misconception is a condition in which students experience a misunderstanding of a concept [23]. An understanding that is not based on scientists or scientific concepts but is believed to be true by students is an indication of a misconception [23]. Misconception can also be explained as an inaccurate understanding of a concept, a wrong understanding of the concept, the use of inappropriate examples when the concept is applied, or a different interpretation of the concept [24]. There are several causes of misconceptions in students. In general, misconceptions that occur in students can come from students' thoughts, textbooks, the internet, friends, or teachers [25]. Students' thoughts about a term can sometimes cause misconceptions. Students who have different thoughts from their teachers during class learning can also cause misconceptions.

2. Four-tier test

In this study, the four-tier test was used to detect students' conceptions which would be categorized into three categories, namely: knowing the concept, misconceptions, and not knowing the concept. The four-tier test was developed on the material of reaction rates and contains multiple chemical representations that include macroscopic, sub-microscopic, and symbolic representations. Four-tier is a type of multiple-choice test that consists of several parts, namely: 1) questions, 2) multiple-choice answers, 3) level of confidence in choosing an answer, 4) reasons for choosing an answer, and 5) level of confidence in choosing a reason [26]. The advantages of the four-tier diagnostic test include: 1) Separating the level of confidence in the answers and the reasons that students choose, which allows for a deeper exploration of students' understanding, 2) Comprehensively detecting misconceptions in students, 3) Indicating areas of material that need additional attention, and 4) Assisting in planning effective learning to address students' misconceptions [27].

The characteristics of the test instrument used in this study were a four-tier multiple-choice test combined with chemical multi-representation, including the first level containing questions and answers, the second level contains confidence in the chosen answer, the third level contains the reasons for choosing the answer, and the fourth level contains confidence in the reasons chosen. The test instrument sheet contains 13 four-tier multiple-choice questions to determine the conception of students whose categories include: know the concept, misconception, and do not know the concept. The test instrument was developed based on Bloom's taxonomy because it is related to students' cognitive abilities, starting from category C2 to category C5.

A four-tier multiple-choice test was developed using indicators and learning objectives for reaction rate. This type of test was chosen because the four-tier multiple-choice test is superior due to the presence of a metacognitive layer (students' confidence in the answers given), which is indeed not found in three-tier and two-tier multiple-choice tests [28]. Thus, teachers can provide in-depth evaluations, not only of students' conceptual understanding, but also assess students' confidence in their answers and detect potential misconceptions comprehensively. In this research, a total of 13 four-tier test questions were developed, covering the rate topics discussed in meetings 1-4, namely: the concept of reaction rate and collision theory, factors that influence reaction rates, and reaction orders. The four-tier multiple-choice test was developed to cover the cognitive levels of Bloom's taxonomy, specifically C2–C5 (understanding, applying, analysing, and evaluating). The developed test questions were then uploaded to the e-learning class.sudutsains.com for students to complete online. The improvement of students' conception is a change in conception that occurs in students after going through a learning process using learning tools that have been developed from not knowing the concept to knowing the concept. Data on the improvement of students' concepts can be obtained through the results of the four-tier multiple-choice test before and after learning.

3. Multiple chemical representations

Multiple chemical representations divide chemistry into three basic levels that must be known. Early research used this concept as one strategy to overcome difficulties in understanding abstract chemical concepts. These three levels of chemical representation consist of the macroscopic level, the microscopic level, and the symbolic level [29]. Multiple chemical representations were first expressed by Santos [30] in the concept of "Three Levels of Chemistry" to help students understand and relate chemical concepts that are often abstract. An overview of the multi-representation approach to chemistry is shown in Figure 2 [31].

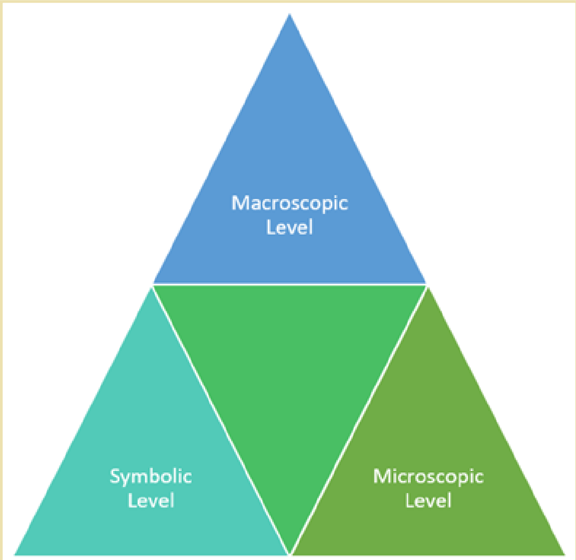

Figure 2 Multiple representations of chemical

Chemical multi-representation includes three levels that play a very important role in chemistry learning, some of which are abstract. The use of chemical multi-representation in chemistry learning has brought several benefits, namely: (1) Improving students' conceptual understanding, (2) Improving students' responses or performance in learning, (3) Reducing cognitive load, (4) Improving students' self-efficacy, (5) Developing students' cognitive structures, (6) Developing students' mental models, and (7) Reducing misconceptions [32].

Some learning media that have been developed with chemical multi-representation on reaction rate material, one alternative that can be chosen is PIMOTS. PIMOTS is an acronym for Preventing Misconception Websites or if interpreted is a website to prevent misconceptions. The advantages of PIMOTS multimedia are easy to access on mobile phones and laptops without downloading, does not require storage space, presentation of material can be with a password, interactive, and can immediately display the scores obtained.

RESEARCH METHODS

The research was conducted on two classes XI-A and XI-B in one of the schools that were determined randomly, before the learning was carried out a pretest was carried out then learning was carried out with an inquiry learning model according to the plan, designed with the support of supporting readings, worksheet, e-learning, supporting videos on the learning website called PIMOTS.

The learning took place in 4 meetings, during the learning process, observations were made of the implementation of the learning plan, student activities during the learning process, and after the learning process, a post-test and questionnaire were conducted. Data is analyzed by calculating the percentage, and then the learning implementation score obtained is interpreted with categories from very bad to very good.

Student activity data is calculated as a percentage, and then the student activity scores obtained are interpreted in categories ranging from poor to very good. The percentage of student response data in the form of "yes" or "no" answers is calculated, and then the student responses are categorized from very unresponsive to very responsive.

Analysis of the increase in students' conceptions is calculated from the results of the students' pretest and posttest using four-tier multiple-choice questions and then categorized into scientific conception, lack of knowledge type 1, lack of knowledge type 2, lack of knowledge type 3, lack of knowledge type 4, misconceptions, false negatives, and false positives. Students' answers based on the criteria of understanding, not understanding or misconceptions are presented using the following equation.

$$P = fN \times 100\ \%$$

Information:

P: percentage number (% group);

f: number of students in each group;

N: total number of students who were used as research subjects.

A comparison was made between the misconceptions that occurred in the pretest and posttest. An increase in misconceptions occurred if, in the posttest, only a few or no students experienced misconceptions. In addition, a comparison of misconceptions was also analyzed from two classes with the same treatment.

Technical description of PIMOTS

PIMOTS (Interactive Platform for Multi-Representation in Reaction Rate Learning) is a web-based digital learning tool designed to support inquiry-based learning using multiple representations (macroscopic, submicroscopic, and symbolic). Technically, PIMOTS is built on a WordPress content management system, integrated with a Moodle Learning Management System (LMS) via interoperability plugins such as Edwiser Bridge. The platform is accessible through both desktop and mobile browsers with a responsive user interface.

PIMOTS is a modular web-based platform designed to support inquiry-based learning in chemistry through the integration of multiple representations. For teachers, the user flow begins with logging into a dashboard where they can create or select learning modules structured around five stages: engage, explore, explain, elaborate, and evaluate. Within each module, teachers can embed interactive elements such as simulations, instructional videos, and quizzes aligned with macroscopic, submicroscopic, and symbolic representations of chemical phenomena. Students access PIMOTS through individual accounts and navigate the learning modules sequentially. They interact with reaction simulations, complete digital worksheets, and answer 4-tier diagnostic questions directly on the platform. All learning activities and assessment responses are automatically recorded and made accessible to teachers via an integrated analytics dashboard.

Technically, PIMOTS is built using a modular architecture. The frontend is developed on WordPress, employing Elementor for flexible visual design. Its backend learning management system (LMS) is powered by Moodle, which is hosted on a dedicated subdomain and synchronized using the Edwiser Bridge plugin. The platform integrates several core plugins to enhance functionality, including H5P for creating interactive content such as simulations and annotated videos, WP-Moodle Sync for managing user accounts and tracking progress, and a custom-built 4-Tier Quiz Module developed using PHP and JavaScript. A MySQL database supports the system's backend, storing student responses, learning analytics, and interaction logs.

Compared to conventional digital learning platforms, PIMOTS offers distinct technical advantages. Its ability to embed manipulable submicroscopic simulations enhances students' conceptual understanding by making abstract chemical processes visually accessible. The integrated 4-tier diagnostic system not only evaluates students' content knowledge but also captures their confidence levels, enabling more accurate identification of misconceptions. PIMOTS is also modular and scalable, designed to integrate seamlessly into existing school LMS infrastructures without requiring system migration. The inclusion of an analytics dashboard provides real-time data on student performance, supporting teachers in making data-informed instructional decisions. Grounded in the principles of Technological Pedagogical Content Knowledge (TPACK) and knowledge integration theory, PIMOTS represents a coherent alignment of content, pedagogy, and technology within a structured digital learning environment.

STUDY RESULTS

1. Results of implementation observations

The results of observations on the implementation of learning in class XI-A and class XI-B are presented in Table 1 below.

Table 1 Learning Implementation

Observation Results	Class XI-A (%)	Class XI-B (%)
Meeting 1	86	90
Meeting 2	86	97
Meeting 3	93	93
Meeting 4	90	90
Average	89	91

The implementation of learning at each meeting was 86% at the first meeting, 86% at the second meeting, 93% at the third meeting, and 90% at the fourth meeting. While the average implementation of learning as a whole in class XI-A was 89%. The implementation of learning in each meeting was 90% in the first meeting, 97% in the second meeting, 93% in the third meeting, and 86% in the fourth meeting. While the average implementation of learning as a whole in class XI-B was 91%.

These results show that the implementation of learning in class XI-A and class XI-B has met the criteria or it can be said that the implementation of learning is by the learning plan, namely the inquiry learning model with a multi-representation approach with the help of PIMOTS multimedia.

2. Result of student activities

The results of observations of student activities are presented in Table 2.

Figure 3 Atmosphere of learning

Table 2 Results of observations of student activities

No	Student Activities	XI-A (%)	XI-B (%)
1	Listening or paying attention to the teacher's explanation.	16	16
2	Open and read	10	9
3	Searching for information related to the material and problem topics	11	10
4	Conducting experiments or observations	20	18
5	Conducting analysis and discussion in the worksheet	14	16
6	Active discussion	13	14
7	Asking questions, opinions	9	9
8	Outside teaching and learning activities	7	8
Total		100	100

The results of the observation of student activities can be seen that during four meetings in class XI-A, the percentage of student activities listening to or paying attention to teacher explanations was 16%, the percentage of students opening and reading worksheets and teaching materials was 10%, the percentage of students looking for information related to material and problem topics was 11%, the percentage of students conducting experiments or observations according to worksheet was 20%, the percentage of students working on analysis and discussion in worksheet was 14%, the percentage of students actively discussing was 13%, the percentage of students asking questions, opinions, or answering questions was 9%, and the percentage of student activities outside of teaching and learning activities was 7%. The total percentage of student activities included in teaching and learning activities is 93% so student activities in class XI-A are categorized as very good.

In class XI-A, the most dominant student activity is conducting experiments or observations according to the worksheet by 20%. Most of the other student activities are also dominated by those involving student activity or student center with a total percentage of 77%. Activities that focus on the teacher or teacher center have a percentage of 16%, namely listening to or paying attention to the teacher's explanation. While activities outside of teaching and learning activities have a total percentage of 7%.

It can also be seen that during the four meetings in class XI-B, the percentage of student activity listening to or paying attention to teacher explanations was 16%, the percentage of students opening and reading worksheet and teaching materials was 9%, the percentage of students looking for information related to material and problem topics was 10%, the percentage of students conducting experiments or observations according to worksheet was 18%, the percentage of students working on analysis and discussion in worksheet was 16%, students actively discussing were 14%, the percentage of students asking questions, opinions, or answering questions was 9%, and the percentage of student activity outside of KBM was 8%. So the total percentage of student activity included in KBM is 92% so student activity in class XI-B is categorized as very good.

In class XI-B, the most dominant student activity is also in the category of conducting experiments or observations according to the worksheet, which is 18%. Activities that focus on students or student centers have a total percentage of 76%. Activities that focus on teachers or teacher centers have a total percentage of 1.6%, namely listening to or paying attention to explanations from teachers, and activities that are outside teaching and learning activities have a total percentage of 8%.

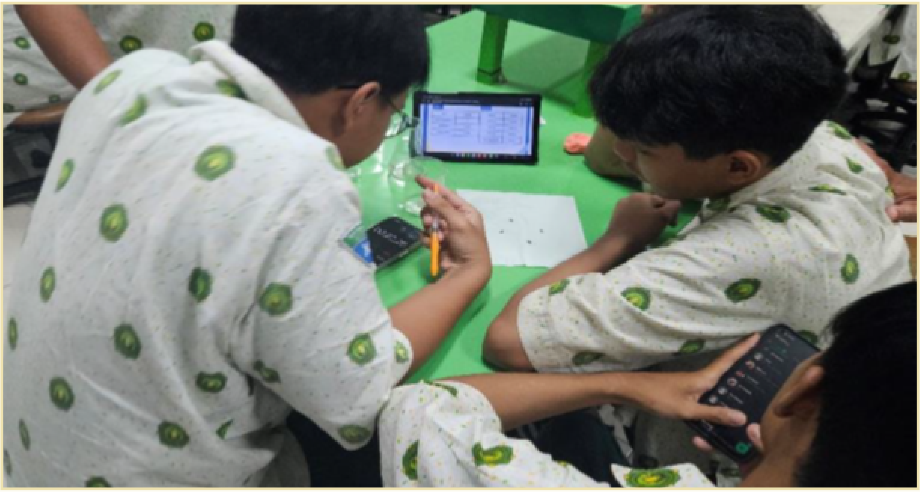

Figure 4 Student activities during learning

Based on the data, it can be seen that most learning activities are focused on students, with three dominant categories: conducting experiments or observations according to the worksheet, working on analysis and discussion in the worksheet, and actively discussing. This is by the concept of inquiry learning, namely prioritizing activities that focus on students in carrying out investigations or observations related to finding a concept in the learning [33; 34]. Inquiry has the potential to increase a person's activity and skills, which involves the process of searching and understanding knowledge to satisfy curiosity. This opinion is in line with the concept of constructivist learning proposed by Vygotsky which emphasizes that the role of the teacher is not to convey knowledge directly to students, but to provide opportunities for students to develop their understanding and express their ideas [35]. The application of inquiry learning with multi-representation content has also been proven to increase students' interest in learning materials, so that students are more active and ask more questions during learning, which will then affect the improvement of understanding of concepts in chemistry learning [36].

3. Student questionnaire results

The results of the student response questionnaire are presented in Table 3.

Table 3 Questionnaire response results

No	Indicator	XI-A (%)	XI-B (%)
1	Interest	86	83
2	Ease of use	91	86
3	Learning outcomes	88	82

The results can be seen from the response of class XI-A students on the indicator of student interest in learning devices at 86%, on the indicator of ease of use at 91%, and on the indicator of learning achievement at 88%. Based on these percentages, it can be stated that class XI-A students responded very well to the inquiry model learning device with multiple chemical representations that had been developed.

The results of the questionnaire show that the response of class XI-B students on the indicator of student interest in learning devices is 83%, on the indicator of ease of use is 86%, and on the indicator of learning achievement is 82%. Based on these percentages, it can be stated that class XI-B students responded very well to the inquiry model learning device with multiple chemical representations that have been used.

The results of the student response questionnaire in class XI-A can be seen that the indicator of student interest obtained a percentage of 86%. This indicates that students are very interested in using inquiry learning devices with multi-representation that have been developed. On this indicator, the highest response stated that students were more enthusiastic about learning using learning websites. The use of websites in learning has been proven to increase students' enthusiasm for learning because of their attractive and interactive appearance and make it easier for them to work on questions [37]. Learning using learning websites has also been proven to increase students' interest in learning [38].

The ease of use indicator obtained a percentage of 91%. This shows that students are very facilitated in learning the reaction rate material by using the learning tools that have been developed. In this indicator, the highest response stated that the instructions for using the learning website and worksheet were clear and easy. The use of worksheets with multiple representations makes students interested in the worksheet design and makes it easier for students to understand the material. In addition, the use of worksheets with multiple representations can guide students in developing reasoning by providing information and scientific evidence in various forms of representation [39].

The results of the student response questionnaire in class XI-B can be seen in the student interest indicator which obtained a percentage of 83%. This shows that students are very interested in using inquiry learning devices with multiple representations when studying reaction rate material. In this indicator, the highest response stated that the learning website with multiple representations was new and the appearance of the worksheet was attractive. The attractive appearance comes from the packaging of the worksheet in general and the chemical multi-representation components in the worksheet include macroscopic phenomena, sub-microscopic illustrations, and graphs or chemical equations that state representations. The existence of various illustrations and displays makes students interested in the worksheet that has been developed. The use of worksheets with multiple representations makes students interested in the worksheet design and makes it easier for students to understand the material.

The ease of use indicator obtained a percentage of 86%. This indicates that students are greatly facilitated in learning the reaction rate material when using inquiry learning devices with multiple representations. In this indicator, the highest student response stated that the existence of a learning website makes it easier to access materials both at home and at school. The e-learning-based learning website is flexible to use because it allows students to access information when they have free time and have a high enthusiasm for learning [26; 37]. In addition, online-based learning makes students more independent and responsible in learning without being accompanied by a teacher [27].

Based on the percentage of the three indicators in the student response questionnaire in the two classes, it can be categorised that students responded very positively to the PIMOTS-assisted inquiry model learning device with multiple representations, having a response percentage score of more than 80% in the two research classes.

4. Result of conceptual change

Changes in students' conceptions can be identified based on a comparison of students' conceptions before and after the use of learning devices with an inquiry model with a multi-representation of chemistry, assisted by multimedia PIMOTS. A comparison of conceptions can be identified from the overall data of students' conceptions during the pretest and posttest. An increase in misconceptions occurs if only a few or no students experience misconceptions in the posttest.

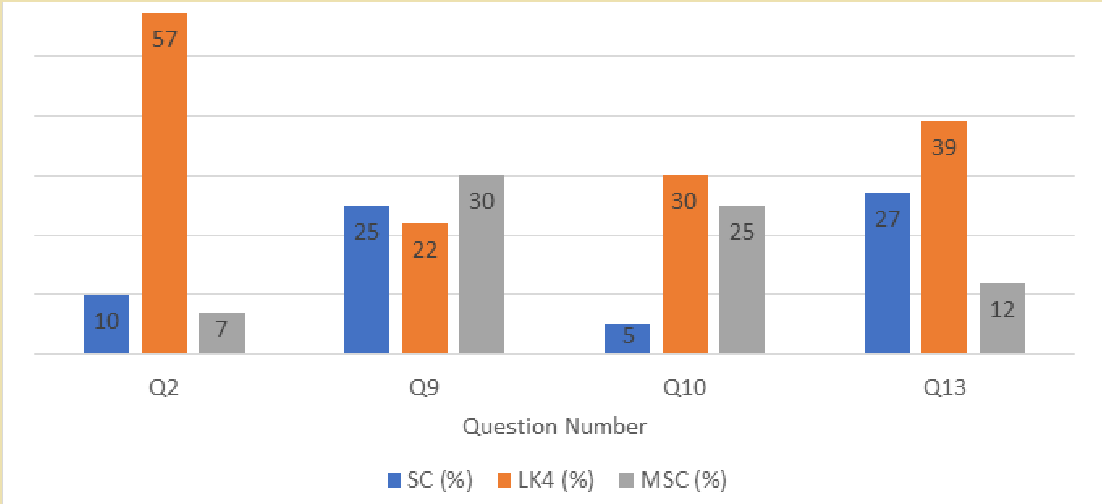

Figure 5 Percentage diagram of class XI-A students' conceptions during the pretest

Based on the diagram in Figure 5, the analysis of the selected pretest items (Q2, Q9, Q10, and Q13) provides a representative overview of students' conceptions before the intervention. On item Q2, more than half of the students (57%) were categorised at the LK4 level, while only 10% reached the scientific conception level, and 7% fell into the misconception category. This finding suggests that most students had not yet built a meaningful understanding of the concept being tested and were still at the stage of fragmented or incomplete knowledge. A different pattern emerged in item Q9, where misconceptions reached 30%, surpassing the proportion of students at the LK4 level (22%) and slightly above those with a scientific conception (25%). This indicates that in certain sub-concepts, students did not merely lack knowledge but actively held incorrect mental models that conflicted with the accepted scientific explanations.

Even more concerning was item Q10, where scientific conception dropped to its lowest level, with only 5% of students answering correctly, while both LK4 (30%) and misconceptions (25%) remained dominant. This shows that misconceptions in this sub-concept were particularly resistant to change, and students' prior knowledge directly interfered with the acquisition of new knowledge. Meanwhile, item Q13 offered a contrasting picture, as the proportion of students with a scientific conception increased to 27%, showing that a small but notable group of students had begun to form a correct understanding. However, LK4 remained the dominant category (39%), and misconceptions were still present (12%), indicating that overall mastery was still limited.

Taken together, these results highlight three key aspects of students' prior conceptions: the predominance of lack of knowledge, the presence of persistent misconceptions in specific sub-concepts, and the early signs of a shift toward scientific conception in certain items. This pattern confirms the constructivist view that misconceptions are not simply the absence of knowledge but represent alternative frameworks that must be confronted and reconstructed through meaningful learning experiences. Without targeted strategies that link new content with students' prior cognitive structures, as provided by the PIMOTS multimedia-assisted inquiry model, the dominance of LK4 and the persistence of misconceptions are likely to remain barriers to conceptual understanding. The percentage data of class XI-B conception during the pretest is shown in Figure 6.

Based on the diagram in Figure 6, the results of the pretest show that students' conceptions in the selected items (Q2, Q7, Q8, and Q13) vary but are still largely dominated by the LK4 category and misconceptions (MSC). On Q2, the proportion of students in LK4 is the highest (57%), while only 10% reached the scientific conception (SC) level. This indicates that most students had not yet developed a solid understanding and were still at the stage of fragmented knowledge. A different pattern appears in Q7, where the percentage of SC is the highest among the selected items (50%). However, a small but consistent portion of students still remain at LK4 (8%) and MSC (15%). This suggests that although many students could form correct conceptions, some still struggle due to incomplete or incorrect prior knowledge. In Q8, misconceptions are very prominent (48%), surpassing both SC (30%) and LK4 (10%). This finding shows that in this sub-concept, students not only lacked knowledge but also held incorrect ideas that conflicted with scientific explanations. Such misconceptions are resistant to change and may interfere with the acquisition of correct knowledge.

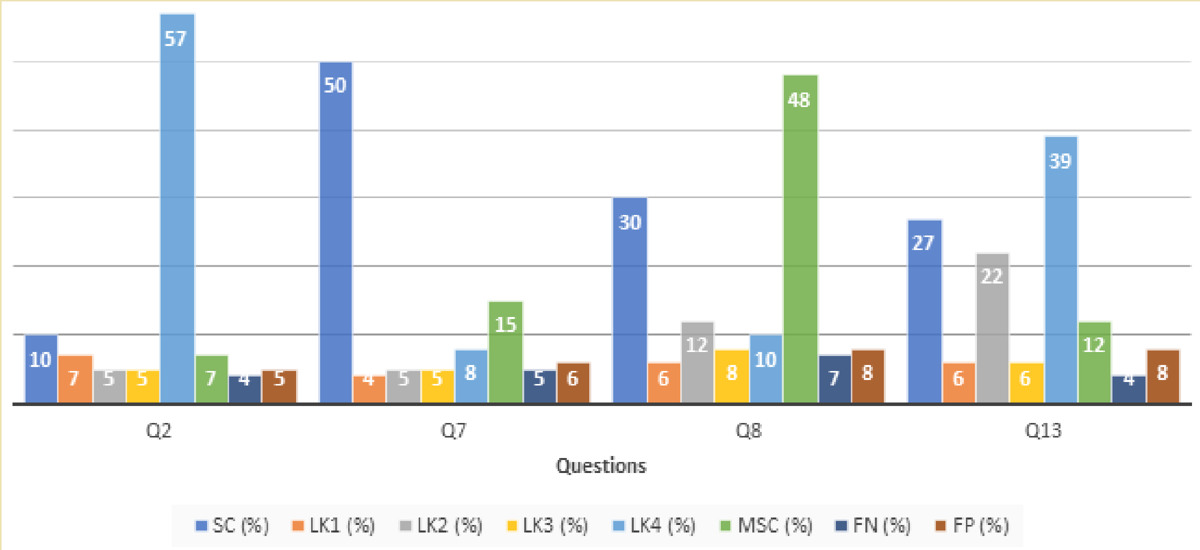

Figure 6 Percentage diagram of class XI-B students' conceptions during the pretest

Finally, Q13 shows a more balanced distribution, with SC at 27% and LK4 still dominant at 39%, while misconceptions remain at 12%. This suggests that although some students had begun to form a correct understanding, the majority were still in the incomplete knowledge category. Overall, the data from these four key questions reinforce the idea that students' difficulties are not only due to limited exposure to the material but also because of persistent misconceptions rooted in their prior knowledge and associative reasoning [28].

In addition, there are many students with various other concepts, including students who already know the concept. This can happen because of intuition or students' luck in guessing [28, 34]. Students convey spontaneous responses without really understanding the question so that it can give rise to various conceptions in the pretest or even the correct answer. After students receive learning using the inquiry model learning device with multi-representation chemistry assisted by PIMOTS multimedia, students work on a post-test to determine their concepts. The percentage data of class XI-A conception during the post-test is shown in Figure 7.

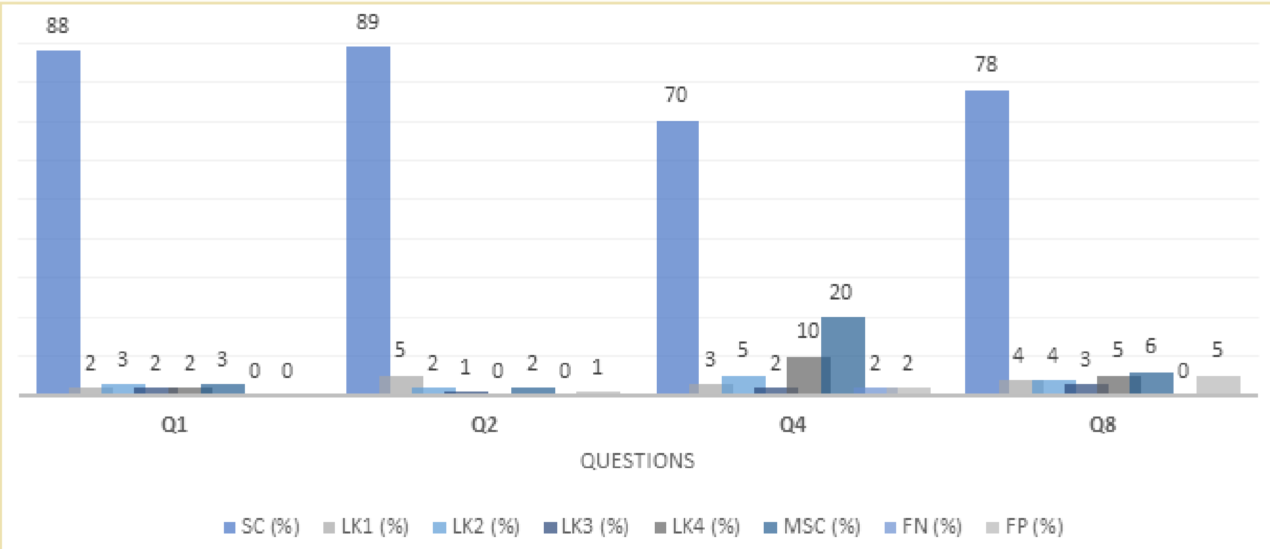

Figure 7 Percentage diagram of class XI-A students' conceptions during the post-test

Based on Figure 7, the posttest results indicate a substantial conceptual shift toward scientific conception (SC) across all items. The percentage of students demonstrating SC ranged from 70% to 89%, making it the dominant category in every question. In Q1 and Q2, SC reached 88% and 89% respectively, while other categories, such as lack of knowledge (LK) and misconceptions (MSC), were reduced to minimal levels, generally below 5%. This suggests that most students were able to internalise and apply scientific concepts with accuracy. In Q4, although SC remained the majority at 70%, there was a noticeable presence of misconceptions (20%) and false negatives (10%). This highlights that certain concepts assessed in Q4 were relatively more difficult for students to reconstruct, with some retaining alternative ideas despite instruction. Meanwhile, Q8 recorded 78% SC with small proportions of false positives (5%) and false negatives (6%), indicating minor inconsistencies but still reflecting a high level of scientific understanding. Overall, the distribution shows that students not only acquired correct scientific knowledge but also successfully replaced previous misconceptions and gaps in understanding. The consistently high SC percentages demonstrate the effectiveness of the instructional approach, while the residual misconceptions in specific items, such as Q4, suggest the need for targeted reinforcement of more complex concepts.

The comparison of pretest and posttest results illustrates three critical outcomes: (1) the dominance of scientific conception after learning, (2) the sharp decline in both lack of knowledge and misconceptions, and (3) evidence of conceptual reconstruction rather than rote learning. These findings provide strong evidence that the PIMOTS multimedia-assisted inquiry learning approach can address the dual challenge of insufficient prior knowledge and persistent misconceptions, thereby supporting the constructivist principle that meaningful learning requires linking new information to and reorganizing existing cognitive structures.

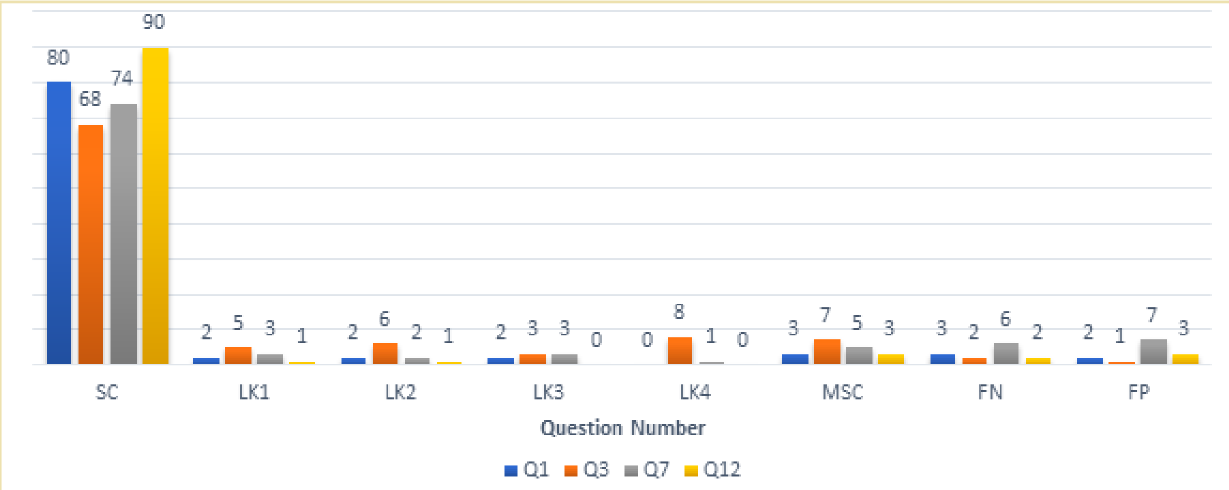

Figure 8 Concept diagram of class XI-B students during the post-test

Based on the diagram in Figure 8 and the percentage data presented, it can be concluded that most students in class XI-B are in the Scientific Conception (SC) category. The percentage of students' scientific understanding is relatively high, with an average score of around 77–78%. The highest score was shown in question number 12 at 89%, while the lowest was in question number 3 at 68%. The majority of other questions fell within the 71–82% range, indicating that students' understanding was quite consistent in answering according to scientific concepts. Meanwhile, other categories such as LK1, LK2, LK3, LK4, MSC, FN, and FP only appeared in small percentages, generally 1–7%, with the highest peak in LK4 at 8%. This indicates that there are some misconceptions or alternative understandings, but they are very limited in number and not dominant. Thus, it can be said that scientific concepts have been mastered by the majority of students, although there are certain questions (especially numbers 3 and 8) that still show weaknesses and need more attention in learning.

Furthermore, changes in students' conceptions were tested using the Wilcoxon ranked sign test. This test was conducted to show changes in concepts that occurred in students due to the implementation of the inquiry model learning device with multiple chemical representations assisted by PIMOTS in chemistry learning. The Wilcoxon test results for conceptual changes in the three classes are shown in Table 4.

Table 4 Wilcoxon test results

Class	Conceptual Change (Pretest & Posttest)	Wilcoxon Signed Ranks	
		Z	Asymp. Sig. (2-tailed)
XI-A	LK 1, LK 2, FP	-2.359	0.018
	SC	-3.192	0.001
	MSC	-2.946	0.003
	LK 3, LK 4, FN	-3.192	0.001
XI-B	LK 1, LK 2, FP	-2.943	0.003
	SC	-3.216	0.001
	MSC	-3.066	0.002
	LK 3, LK 4, FN	-3.187	0.001

Based on the results of the Wilcoxon test on the conceptions of students in grades XI -A, and XI-B during the pretest and posttest in Table 4, the significance values vary and are all below 0.05. This indicates that there is a change in the overall conception of students in grades XI -A and XI-B which includes the conception of lack of knowledge type (LK 1), lack of knowledge type 2 (LK 2), lack of knowledge type 3 (LK 3), lack of knowledge type 4 (LK 4), false positive (FP), false negative (FN) – where students confidently provide incorrect answers, misconception (MSC) which is reflect deeply about scientifically inaccurate beliefs, and know the concept (SC).

In Figure 7, it can be seen that the conception of students in class XI-A during the posttest was mostly in the scientific conception or knowing the concept with an average of 75% for all questions. This conception occurs when students choose the correct answer and reason with a high level of confidence. However, there are also students in class XI-A who have other categories of conception such as students who know the concept but are not confident or have poor reasoning, namely in the category of lack of knowledge type 1, lack of knowledge type 2 (LK 2), and false positive with an average of 4% for all questions. Students in class XI-A who do not understand the concept correctly are in the category of lack of knowledge type 3 (LK 3), lack of knowledge type 3 (LK 3), and false negative with an average of 2% for all questions. Meanwhile, students in class XI-A who experience misconceptions have an average of 6% for all questions.

In Figure 8, it can be seen that the conception of students in class XI-B during the posttest was mostly on the concept of knowing the concept (scientific conception) with an average of 78% on the overall questions. Meanwhile, students in class XI-B who understand the concept but are not confident in their answers or their reasons are not quite right are in the category of lack of knowledge type 1 (LK 1), lack of knowledge type 2 (LK 2), and false positives are 3% on the overall questions. Students in class XI-B who do not understand the concept are in the category of lack of knowledge type 3 (LK 3), lack of knowledge type 3 (LK 3), and false negatives on average for the overall questions, namely 3%. Meanwhile, students in class XI-B who experience misconceptions are 4% on average for the overall questions.

Scientific conception or concept knowledge category occurs when students choose the correct answer and reason with a high level of confidence in the choice of answer and the reason. Students in this category do not experience difficulty in understanding the concept to continue to the following material [29]. Students can be in this conception because they have fully understood the reaction rate material that has been delivered through inquiry model learning with multiple chemical representations assisted by PIMOTS.

Meanwhile, students in the concept of lacking knowledge type 1 (LK 1), lacking knowledge type 2 (LK 2), and false positive categories already know the presented idea, as their answers are correct in these categories. However, the reason students are in this category is due to incorrect reasoning, specifically in the category of lacking knowledge type 2 (LK 2) and false positives. This can happen because students are either unable or fail to formulate logical and complete reasoning, leading them to choose the wrong reason. Meanwhile, students in the category of lacking knowledge type 1 (LK 1) are correct in choosing questions and answers, but still have a low level of confidence. This can happen because students worry about choosing the wrong answer. Students in this category can be helped to achieve the scientific conception category by increasing their self-confidence, such as allowing them to answer in front of the class, speaking during presentations, and giving awards or rewards after answering questions or quizzes [29].

Students in the concept of knowledge deficit type 3 (LK 3) and false negative exhibit incorrect answers with low confidence, despite correct reasons. In contrast, those in the concept of knowledge deficit type 4 (LK 4) display both incorrect answers and proper reasons. Students in this concept do not understand the idea or material that has been presented so they can relearn the material [29, 36]. Meanwhile, students who experience misconceptions have wrong answers and reasons, but they have high confidence in those answers and reasons. Students in this category can be given a re-explanation of the correct material or concept. There are several causes of students experiencing misconceptions that require more data and in-depth research because handling misconceptions due to associative thinking is different from students who experience misconceptions due to humanistic thinking or wrong intuition [30].

When viewed from the observation results, various conceptions other than scientific conception or knowing the concept can occur because in the observation of the implementation of learning there are still activities outside of teaching and learning, such as teachers who only focus on a few students, cannot answer student questions, and cannot create a conducive class. In the results of observations of student activities as a whole in each class, activities that do not support learning are also found, such as being bored and not enthusiastic about participating in learning, being busy with friends, and not paying attention to the teacher.

All activities outside of teaching and learning activities, both those carried out by teachers and students, can hinder learning, thereby reducing the essence of meaningful learning, which can ultimately lead to various conceptions from students. The category of conceptions or understanding of student material that is diverse can also be caused by internal factors of students, namely lack of learning motivation, intelligence, and different talents or interests [31]. However, overall, there was a change in students' conceptions of scientific conceptions or knowledge of the concept of the reaction rate material after learning with the developed learning tools. Very significant. This is also supported by Table 4 on the results of the Wilcoxon test for the three classes in the four categories of conception (know the concept, know the concept but are not confident in their answers, do not know the concept, and misconceptions) stating that there is a significant change in conception on the pretest and posttest scores of students because it has a significance value of <0.05. Where the scientific conception or knowledge of the concept increased while other conceptions decreased in the posttest.

This is to previous research which states that learning using a guided inquiry model and a multi-representation approach is effective in increasing understanding of the material presented because learning is delivered through macroscopic, sub-microscopic, and symbolic representations in their entirety with a learning model that focuses on students [32]. In addition, high school students who are just starting to study chemistry will have difficulty understanding chemical material if they cannot link the three chemical representations, so learning is needed that bridges the three representations, including macroscopic phenomena in everyday life, sub-microscopic modeling, and symbolic [33].

Based on the explanation above, it can be seen that students who experienced a change in conception to scientific conception or knew the concept at the end of learning increased significantly so it can be stated that the inquiry model learning device with multi-representation assisted by PIMOTS multimedia can be used to prevent misconceptions in the material on reaction rates.

DISCUSSION

The results of this study indicate a significant change in students' conceptions of reaction rates after the implementation of the PIMOTS-assisted inquiry learning model with multiple chemical representations. This finding is in line with previous research that emphasizes the effectiveness of inquiry-based learning in promoting conceptual understanding and reducing misconceptions in chemistry learning [43]. The increase in the percentage of students achieving scientific conception shows that learning activities that integrate macroscopic, submicroscopic, and symbolic representations can strengthen students' mental models and bridge abstract concepts into meaningful understanding [44].

The results of the four-tier diagnostic test provided a detailed insight into the transformation of students' misconceptions. The reduction in false positives, false negatives, and various types of knowledge deficits (LK1–LK4) reflects how the learning design fosters not only correct answers but also metacognitive confidence in reasoning. This supports the notion that multi-tiered diagnostic instruments can reveal deeper cognitive structures beyond surface-level performance [45; 46]. Moreover, this improvement demonstrates that PIMOTS, which facilitates integrated multimedia representations, enhances students' learning experiences by accommodating various learning styles [47; 48].

The student-centred approach in inquiry learning, as reflected in high student activity percentages, plays a critical role in supporting constructivist learning environments. Students were engaged in analysing, experimenting, and discussing, which are core elements of scientific inquiry [49; 50]. This active involvement not only builds cognitive engagement but also fosters scientific reasoning skills. The use of digital platforms like PIMOTS also contributes to increasing students' motivation and flexibility in accessing content, as supported by recent studies on e-learning tools in science education, as done by Yang et al [51].

Despite these encouraging results, several challenges remain. There are still students that while the PIMOTS-based model addresses many cognitive barriers, there is a need for complementary interventions, such as formative feedback sessions or peer-assisted learning, to further reduce persistent misconceptions. The variation in conceptual changes between classes also points to the influence of teacher facilitation and classroom management, as highlighted by observational data. Therefore, teacher training in managing inquiry-based, technology-integrated classrooms becomes essential [52].

The findings of this study demonstrate that implementing an inquiry-based learning model supported by PIMOTS, incorporating macroscopic, submicroscopic, and symbolic representations, significantly enhances student engagement, scientific conception, and metacognitive confidence. These results align with previous research showing that online inquiry environments can improve engagement and learning outcomes among secondary students, as demonstrated in studies by Al Mamun et al [53]. The integration of multiple representations in PIMOTS also supports constructivist pedagogy, which is central to effective chemistry education [54; 55], and aligns with 21st-century learning skills such as critical thinking, collaboration, and scientific reasoning.

Comprehensive training for teachers is essential to scaffold inquiry processes and effectively utilize PIMOTS in classroom instruction. Teachers should be equipped with strategies to stimulate productive cognitive conflict without overwhelming students ensuring meaningful conceptual change while maintaining motivation. Furthermore, school leaders and policymakers should consider embedding PIMOTS within school-wide digital learning frameworks and Learning Management Systems (LMS). Standardized modules and interactive activities integrated into LMS platforms have been shown to significantly enhance student interaction and engagement. To ensure long-term use, PIMOTS should be designed to integrate with existing LMS (e.g., Moodle, Schoology) using modular and scalable architecture. Features such as plugins and APIs allow for platform flexibility and adaptability across different institutional contexts.

PIMOTS should be hosted on school LMS platforms to allow teachers and students continuous access to resources, peer interaction, and advanced features such as quizzes, discussion forums, and virtual labs. LMS-based integration can enable the use of learning analytics to track student activity, identify misconceptions early, and provide targeted feedback. Early learning behavior data also supports more informed instructional decisions. To ensure relevance over time, the PIMOTS platform should be continuously updated with new questions, visual representations, simulations, and guided experiments. Supporting teacher development modules can help maintain and expand content collaboratively. Finally, ongoing evaluation is recommended to measure long-term retention of chemistry concepts and assess the scalability of PIMOTS across topics and student populations. Regular feedback from users teachers and students alike will support iterative improvements of both content and platform functionality.

Overall, the integration of multimedia, multiple representations, and inquiry learning proves to be a powerful pedagogical strategy. It aligns well with 21st-century learning demands, emphasizing critical thinking, conceptual reasoning, and technology integration. Future research may explore long-term retention effects and the scalability of PIMOTS in different chemistry topics or diverse student populations.

CONCLUSION

The results of this study show that the implementation of learning in both research classes met the intended criteria and aligned with the lesson plan. Student engagement during the learning process was very high, indicating that the teaching was student-centred. Observational data and student activity records confirm that learners were actively involved in inquiry-based activities supported by multi-representation. Additionally, the questionnaire results revealed that students responded positively to the learning experience. This reflects a high level of interest in the multi-representation-based instruction using the PIMOTS-assisted inquiry model.

A comprehensive change in student conception was observed across both experimental classes. This change was evident in the transformation of various types of conceptual errors, such as lack of knowledge type 1 (LK1), type 2 (LK2), type 3 (LK3), and type 4 (LK4), as well as false positives, false negatives, and general misconceptions into accurate scientific conceptions. The increase in scientific understanding, as measured through the four-tier diagnostic tests, demonstrates that students developed more meaningful conceptual frameworks of reaction rate material by the end of the learning process. Therefore, it can be concluded that the inquiry-based learning tools supported by PIMOTS multimedia are effective in minimising and preventing misconceptions in the topic of chemical reaction rates.

Based on these findings, it is recommended that chemistry teachers participate in professional development programs or enrichment workshops that incorporate digital diagnostic instruments and multi-representational strategies. Such training can enhance teachers' ability to clarify abstract chemistry concepts and help students develop a deeper and more accurate understanding. Moreover, teachers should give greater attention to students' common misconceptions in chemistry lessons by applying early diagnostic tools, such as questionnaires or structured group discussions, at the beginning of instruction. These practices can lead to more targeted teaching and significantly improve learning outcomes.

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