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# EXPLORING THE REPRESENTATIONAL COMPETENCE OF ELEVENTH-GRADE STUDENTS ON THE RATES OF CHEMICAL REACTIONS

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**ABSTRACT**

Representational competence is a key component in learning chemistry, allowing students to interpret and apply multiple forms of representations to explain scientific phenomena. Such competence supports deeper understanding, improved communication, and stronger problem-solving abilities. This study aims to examine eleventh-grade students' representational competence on the topic of chemical reaction rates. Data were collected using short-answer questions to assess the representational competence of students under five aspects: 1) interpreting the meanings of chemical representations; 2) translating between different representations at the same level; 3) translating between different representations across levels; 4) using representations to generate explanations; and 5) connecting between representations and concepts. Descriptive statistics (mean, percentage, and standard deviation) were used for analysis. The results revealed an overall average score of 11.97 out of 30 (39.91%), indicating a moderate level of competence. While 78.95% of students performed at a moderate level and 21.05% at a low level, none reached a high level. Average scores by component showed moderate levels for interpreting representations (60.96%), generating explanations (51.75%), translating across levels (41.23%), and within levels (33.33%). The lowest performance was exhibited for connecting representations with concepts (12.28%), categorized as low. The findings suggest that students struggle particularly with integrating representations and concepts. Therefore, educators should design learning activities that explicitly connect multiple representations to conceptual understanding. This study provides insight into specific areas of difficulty and highlights the need for instructional strategies that target representational competence in abstract chemical topics, offering a practical contribution to chemistry education.



Keywords: representative competency; scientific conception; scientific understanding; alternative conceptions

## INTRODUCTION

The Sustainable Development Goals (SDGs), established by the United Nations, aim to address critical global challenges, including social inequality, economic instability, and environmental degradation, by 2030 (Mishra et al., 2023). Among these, SDG 4: Quality Education is considered a foundational goal for all other goals. It provides students with inclusive, equitable, and effective education and learning opportunities, enabling students to acquire competencies and skills to ensure a sustainable future and lifelong learning (García et al., 2020). Science education, with chemistry as an important focus, supports these competencies through scientific literacy, problem-solving capacities, and innovation capacities, all of which are critical competencies for solving contemporary global challenges, including climate change, clean energy transition,

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and sustainable industrial development (Anastas et al., 2021; Fu et al., 2024). Chemistry education is vital for sustainability, helping students to engage with complex issues and drive innovation in areas like renewable energy, green materials, and clean technologies (Kharissova et al., 2019). For example, scientific breakthroughs in hydrogen fuel cells and lithium-ion batteries contribute to reducing reliance on fossil fuels (Badawi et al., 2025), while developments in biodegradable plastics and advanced recycling technologies support circular economies (Moshood et al., 2022). Developing representational competence is critical for effectively teaching chemistry. Teaching chemistry is not simply about recalling facts in memory; students are expected to visualize phenomena in the realm of chemistry. Learning to create and interpret representations within chemistry is essential (including "big picture" constructs and molecules, plus symbols of chemicals in an implicit way). If students can connect various levels of representations, they are more likely to use their learning in scientific situations and everyday life.

Chemistry involves understanding matter through abstract concepts and changes observed in nature (Speight, 2019; Taber, 2019). According to Johnstone (1993), the chemical framework identifies three levels of representation: macroscopic, microscopic, and symbolic. Chemists use models, diagrams, and equations to convey these concepts (Becker et al., 2015; Amalia et al., 2018). Students who can interpret and connect these representations across levels can better grasp concepts and express their understanding clearly (Rosyida et al., 2022). In order for students to use their chemical knowledge effectively in science and everyday contexts, they need to be able to generate, interpret, and translate representations at all three levels (macroscopic, microscopic, and symbolic). This means that they can effectively relate their theoretical learning to the real-life context (Daniel et al., 2018). This competence allows learners to express and connect chemical ideas in coherent and scientifically accurate ways; just as importantly, it allows them to understand intricate phenomena, make informed choices, and innovate in a range of areas, especially concerning social and environmental challenges. Ultimately, representing competency is foundational to scientific reasoning, systems thinking, and sustainable problem-solving (Pande & Chandrasekharan, 2022; Edelsbrunner et al., 2024). This skill becomes especially crucial when learning abstract and dynamic topics such as reaction rates, taking on increased significance because it requires students to connect observed phenomena (e.g., color change, gas evolution) with molecular-level processes and quantitative data representations. Many students typically have difficulty making the desired connections; consequently, they often build an incomplete or shallow grasp of chemical kinetics (Stroumpouli & Tsaparlis, 2022; Nickel et al., 2025). Therefore, strengthening representational competence is not only important for conceptual learning in chemistry but also vital for enabling students to address real-world scientific concerns and contribute meaningfully to sustainability goals.

According to Sim and Daniel (2014), representational competence comprises five interconnected aspects: AS1-interpreting the meanings of chemical representations, including macroscopic physical properties, microscopic molecular behavior, and symbolic forms like equations; AS2-translating between representations at the same level, such as connecting observations with molecular diagrams or equations; AS3-translating between representations across different levels (macroscopic, microscopic, symbolic); AS4-using representations to construct scientific explanations; and AS5-connecting representations with scientific concepts by integrating information across multiple levels to explain a phenomenon. This competence supports deeper learning by clarifying abstract ideas and improving the application of scientific knowledge (Stieff & DeSutter, 2021). Students with strong representational skills better understand complex ideas, are good problem solvers, and can explain their thinking (Volkwyn et al., 2020; Edelsbrunner et al., 2023), while limited skills can lead to persistent misconceptions (Sarıtaş et al., 2021).

While the importance of representational competence in science education is widely acknowledged, Thai studies continue to highlight persistent challenges in fostering this skill. Many students struggle to represent and include chemical symbols, limiting their conceptual understanding (Suknarusaithagul et al., 2021). Although teaching strategies like model-based learning and multiple representations are effective (Farida et al., 2017), they are not being used across the classrooms in Thailand. Active learning strategies (collaboration, problem-solving, and hands-on activities) support representational and conceptual growth (Kwangmuang et al., 2021). However, teaching strategies often do not connect science content to the everyday life of students, reducing engagement and problem-solving ability and producing negative consequences on learning outcomes (Ahmad et al., 2021; Suriyabutr & Williams, 2021; Yangjeen et al., 2021). The continued drop in Thai students' average scores in the PISA scientific assessments from 2018 to 2022 indicates ongoing challenges in relation to science education (OECD, 2023). These challenges can partly be attributed to the fact that many teachers are still using a teacher-centered way to teach science. Although it may be assumed that lecture-based delivery is efficient because the content seems to be delivered to students, teacher-centered instruction does not promote higher-order thinking, nor does it promote students' representational competence. This disconnect presents a critical barrier to achieving the goals of competency-based education and hinders students' preparedness to participate in solving sustainability challenges through science. In addition, an analysis of students' worksheets and observations of the classroom has provided evidence that many students were unable to explain chemical phenomena with the representations in front of them, such as when asked to interpret graphs or relate reaction diagrams to the associated chemical equations. Furthermore, even the students' midterm exam scores indicated a low level of understanding. Taken together, the evidence suggests a chronic lack of representational competence, indicating a widespread inability to understand basic scientific principles, such as chemical concepts, which are known to support conceptual understanding. If not resolved, this could negatively impact students' grasp of foundational science concepts.

Despite its importance, most existing studies on representational competence focus on undergraduate students and limited topics, such as organic chemistry or basic concepts like elements and solutions (Stull & Hegarty, 2016; Derman & Ebenezer, 2020; Magana et al., 2024). In the Thai context, there is a notable lack of research examining such competence across different chemistry topics, educational levels, or through the development of competency models. This gap underscores the urgent need for context-specific studies to expand understanding and improve instructional strategies. Doing so will support deeper conceptual learning in less-explored areas of chemistry and contribute meaningfully to advancing science education in Thailand.

Therefore, this study aims to assess the representational competence of eleventh-grade students on the topic of chemical reaction rates. This study fills a knowledge gap concerning students' representational competence, a topic scarcely explored within the context of secondary science education in Thailand. The researchers hope that this study will provide valuable and fundamental data essential for planning and developing teaching strategies, as well as instructional materials in the future, to effectively enhance students' conceptual understanding and scientific skills in the field of chemistry. In doing so, the study contributes not only to improving chemistry education practices but also to advancing SDG 4 and supporting the broader goal of equipping learners to engage in sustainable scientific and societal development.

## METHODS

This study employs a basic quantitative design (Creswell & Guetterman, 2019) to explore the representational competence of students. The participants in this study consist of 38 eleventh-grade students from Sarakhampittayakhom School, Mahasarakham, Thailand, in the second semester of the academic year 2024. A convenience sampling technique was used, with participants selected based on accessibility and willingness to participate. At this school, students in each grade level are assigned to classrooms with mixed academic abilities and follow the same curriculum and assessment standards. Therefore, the sampled class reflects the typical academic distribution and learning context of the entire Grade 11 student population at the school. As such, the results can be considered strongly representative of this population and provide reliable insights for informing teaching and learning within the school context. Participation was entirely voluntary, with informed consent obtained from all students.

The research instrument consisted of 15 items in a short-answer representational competence test focusing on the topic of chemical reaction rates. The test consisted of contextualized scenarios and was designed to assess five aspects of representational competence (Sim & Daniel, 2014): AS1-interpreting the meanings of chemical representations, AS2-translating between representations at the same level, AS3-translating between representations across levels, AS4-using representations to construct scientific explanations, and AS5-connecting representations to underlying chemical concepts. The test was reviewed by experts for content validity using the Item-Objective Congruence (IOC) index, with values ranging from 0.67 to 1.00, and its overall appropriateness was rated between 4.51 and 5.00 on a 5-point Likert scale. To ensure reliability, the test was piloted with a group of students with similar characteristics, and the internal consistency was assessed using Cronbach's alpha, which yielded a value of 0.71. This indicates an acceptable level of reliability for educational research. For this study, students were assessed using a scoring rubric consisting of five key components aligning with the elements of representational competence. Each component was carefully designed to measure specific competencies identified in the research related to students' representational competence. Each aspect was rated on a scale from 0 to 2, where 0 indicated no relevant response, 1 reflected partial understanding, and 2 represented a complete and accurate performance. This scoring system captured how correct and thorough the students' ideas were. By looking at these scores, the rubric helped the researcher to understand how well the students interpreted, connected, and used visual and symbolic representations to explain chemical phenomena at various levels.

The collected responses were scored using a rubric scoring method adapted from Sim and Daniel's framework. Quantitative data were analyzed using descriptive statistics, including mean and standard deviation, for both overall performance and each individual component. Final scores were converted to percentages and categorized into three levels of representational competence: low (<25%), moderate (25–75%), and high (>75%). This approach allowed for a detailed interpretation of students' strengths and weaknesses in representational understanding. The researcher then extracted key statements, categorized the answers, and grouped similar or contrasting ideas. This made it possible to uncover deeper knowledge, which might not be available through quantitative analysis alone. In this way, the researcher was able to further understand the process of thinking, explanation, and perspective of the students in each aspect of representational competence.

## RESULTS AND DISCUSSION

This study assessed the level of representational competence among 38 eleventh-grade students. The results of this assessment are presented in Table 1, providing a summary of students' overall performance across the measured dimensions.

**Table 1.** Number of students at each level of competence

| Level of Representational Competence | Score (%) | Number of Students |
|---|---|---|
| High | >75 | 0 (0.00%) |
| Moderate | 25-75 | 30 (78.95%) |
| Low | <25 | 8 (21.05%) |

As presented in Table 1, none of the students achieved a high level of representational competence. A total of 30 (78.95%) students demonstrated a moderate level, while the remaining 8 (21.05%) were classified at a low level.

Considering the number of students at each level of competence for each aspect, AS4 had the highest proportion at the high level, with 11 students (28.95%). In contrast, AS2 had the lowest, with no students (0.00%) achieving a high level. At the low level, AS5 had the highest number of students, with 28 (73.68%), whereas AS1 had the fewest, with only 1 (2.63%) student. Overall, the majority of students across the aspects demonstrated a moderate level of competence. However, AS5 stood out as the only aspect where most students were categorized at the low level, as illustrated in Figure 1.

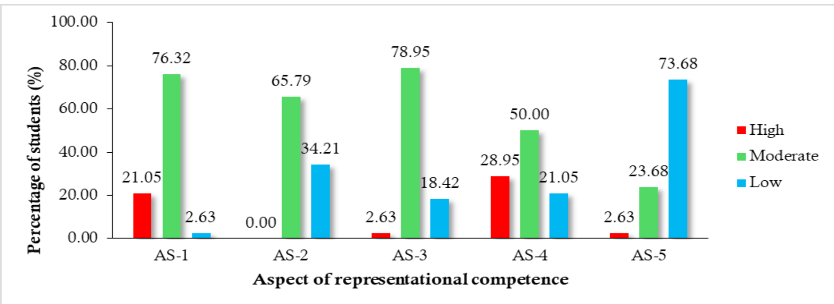



**Figure 1.** Percentage of Students at Different Levels in Each Aspect of Representational Competence

Moreover, when considering each aspect, the scores of AS1, AS2, AS3, and AS4 fall within the moderate level of competence, indicating that students demonstrate a moderate degree of understanding and ability in these areas. In contrast, AS5 recorded a marked fall within the low competence level. These results are summarized in Table 2.

**Table 2.** Descriptive statistics for representational competence aspects

| Aspect | Full Score (Points) | Mean | Standard Deviation | Average Score (%) | Level of Representational Competence |
|---|---|---|---|---|---|
| AS1 | 6.00 | 3.66 | 1.34 | 60.96 | moderate |
| AS2 | 6.00 | 2.00 | 1.19 | 33.33 | moderate |
| AS3 | 6.00 | 2.47 | 1.25 | 41.23 | moderate |
| AS4 | 6.00 | 3.11 | 1.97 | 51.75 | moderate |
| AS5 | 6.00 | 0.74 | 1.45 | 12.28 | low |

The study of average scores across representational competency elements reveals additional areas of relative strength and weakness across students. AS1 produced the highest average score (M = 3.66, 60.96%), indicating that students were moderately skilled at identifying and comprehending the meaning of presented visual or symbolic representations. This reflects the findings by Kozma and Russell (2005), who emphasized that students often begin developing representational competence by interpreting rather than producing representations. Similarly, AS4 also showed a moderate level (M = 3.11, 51.75%), indicating that many students could connect their explanations with the chosen representations, especially when those representations were self-generated or familiar. However, AS2 and AS3 had lower average scores (33.33% and 41.23%, respectively), indicating continued issues in making representational connections. This is a known difficulty in chemistry education where macroscopic, microscopic, and symbolic levels are frequently unconnected in instruction (Johnstone, 1993). Most notably, AS5 had the lowest average (M = 0.74, 12.28%), revealing a clear gap in the students' ability to employ diverse representations in their explanations. To address this, chemistry teachers should implement tactics such as representation translation assignments, multi-level idea mapping, and scaffolded prompts that require students to explicitly connect across representation types(Ainsworth, 2006; Talanquer, 2011). Additionally, think-aloud modeling would be beneficial, where teachers vocalize their thought process while transitioning between representations. This approach helps students internalize the skills of expert representation(Chittleborough & Treagust, 2008). These approaches can foster the deeper integration of representational forms and support students in constructing more cohesive scientific explanations.

Furthermore, an analysis of students' responses to the representational competence assessment revealed that many students lacked sufficient conceptual understanding. This limitation hindered their ability to effectively demonstrate

representational competence. Illustrative examples of student responses for each aspect are presented below.

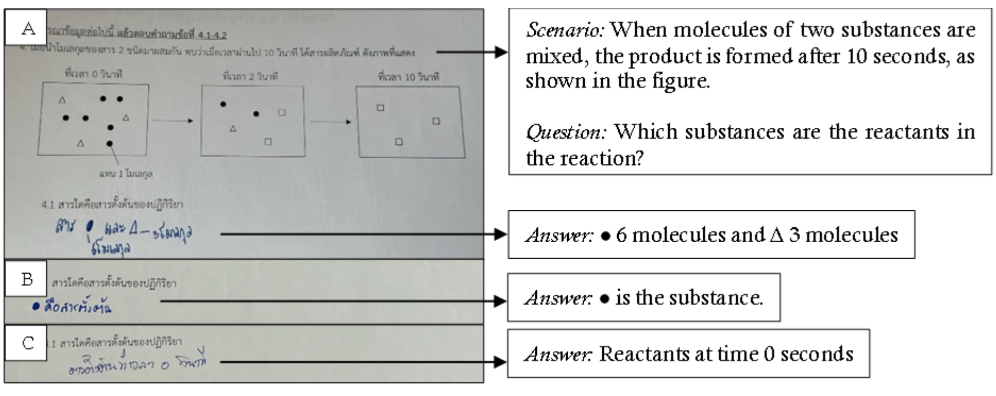



**Figure 2.** Examples of Student Answers in Interpreting the Meaning of Representations (AS1)

The analysis of students' responses concerning their ability in AS1 revealed an interesting point from the scenario shown in Figure 2. High-performing students were able to clearly articulate the meaning of the representations. They demonstrated a solid understanding of chemical changes, correctly identified the types of substances involved, and recognized the relationship between reactants and products, as shown in Figure 2A. However, a portion of students showed incomplete understanding, providing only partial explanations, as shown in Figure 2B, or unclear explanations that did not fully address the question, as shown in Figure 2C. This suggests potential gaps in their grasp of fundamental chemical concepts.

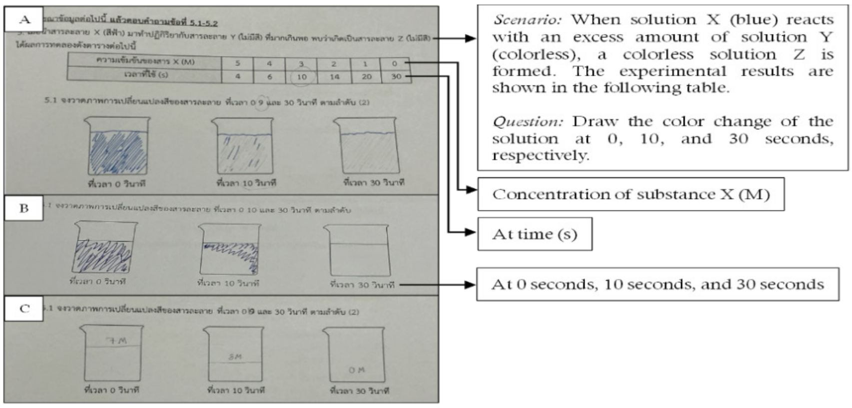



**Figure 3.** Examples of Student Answers in Translating between Representations at the Same Level (AS2)

An insightful observation emerged from the analysis of students' responses aimed at AS2, based on one of the assessment scenarios, as illustrated in Figure 3. Students with high ability in this area could correctly and comprehensively connect the relationship between concentration and the color of the solution, which fades over time, as shown in Figure 3A. However, there were still students who had several significant misconceptions. For example, some students mistakenly interpreted a decrease in concentration as a reduction in the volume of the solution, as shown in Figure 3C. This reflects a lack of understanding of the important distinction between quantity and concentration. Additionally, some students misinterpreted color changes in solutions, believing that a less intense color indicated a clear separation between colored and colorless regions, rather than a uniform fading of color, as shown in Figure 3B. Such misconceptions indicate that students had yet to fully comprehend the molecular-level distribution of substances within solutions.

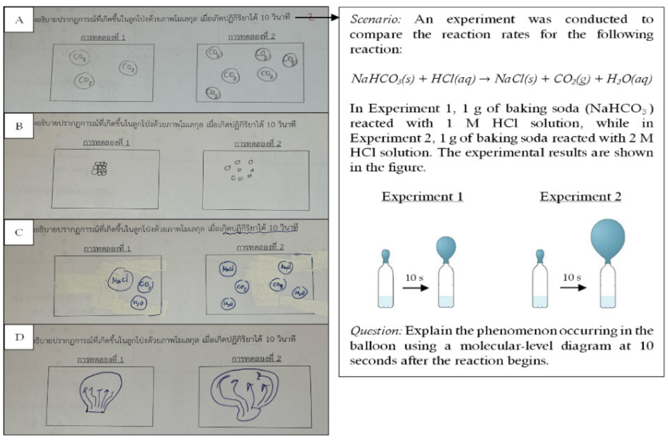



**Figure 4.** Examples of Student Answers in Translating between Representations at Different Levels (AS3)

When analyzing students' responses to assess their ability in AS3, an interesting finding emerged from the analysis of one of the scenarios used in this assessment, as shown in Figure 4. The findings highlighted that students with this high ability could correctly and comprehensively explain the phenomenon of balloon expansion using molecular-level diagrams. The diagrams show different numbers of gas molecules inside the balloons in both experiments and clearly indicate that the molecules shown are $CO_2$, as illustrated in Figure 4A. Some students had several misunderstandings. For example, they believed that the balloon's inflation was caused by changes in the arrangement of molecules (such as molecules being closer together or farther apart) rather than by an increase in the number of gas molecules, as shown in Figure 4A. This reveals an incomplete understanding of kinetic molecular theory and the relationship between the number of gas molecules and the volume of gas. Moreover, some students erroneously included non-gaseous substances, such as solutions or ions, inside the balloon in their representations, as shown in Figure 4B, indicating confusion about the properties of different states of matter. Finally, example responses from students who were unable to use molecular diagrams to explain the phenomenon did not include drawings of molecules and the correct identification of the molecules, as shown in Figure 4C.

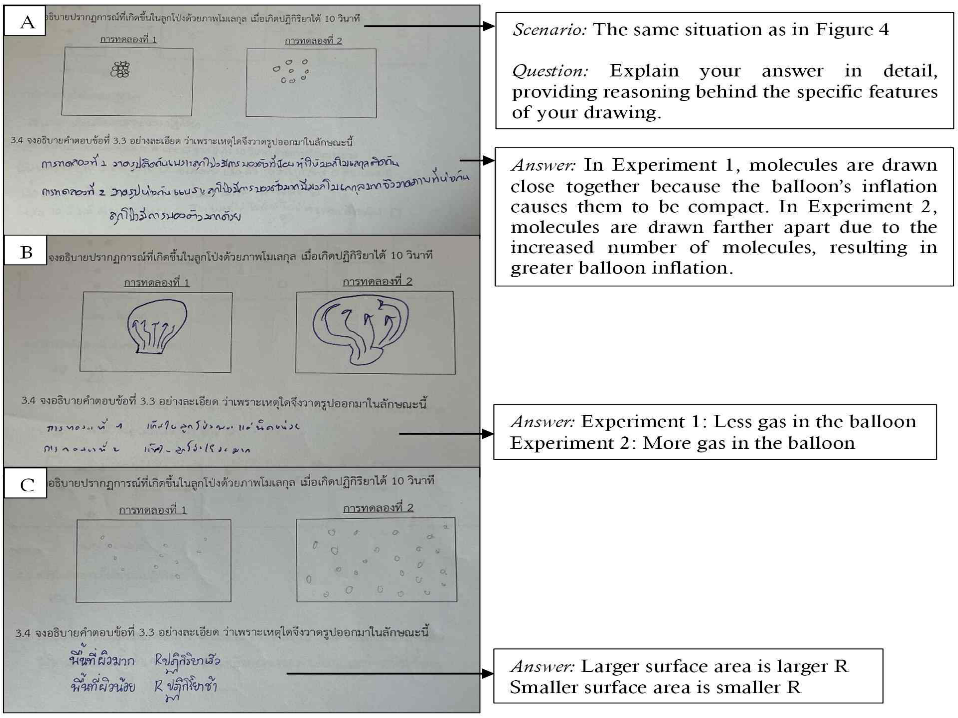
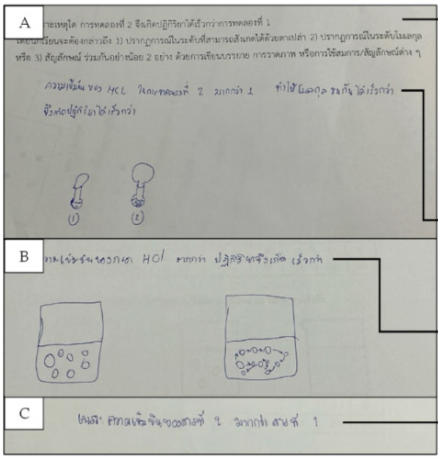



**Figure 5.** Examples of Student Answers in Using Representations to Generate Explanations (AS4)

An interesting finding regarding students' ability in AS4 emerged from the same scenario discussed in AS3, as shown in Figure 4, with the question shown in Figure 5. The evaluation of students' ability to use representations to generate explanations focused on the consistency between their intended explanations and the representations they produced, rather than the accuracy of their chemical knowledge. Even when students held misconceptions, they could receive full credit if their molecular-level drawings coherently reflected their intended explanation. For instance, a student who incorrectly believed that balloon inflation resulted from molecular rearrangement could still effectively communicate this idea through a clear drawing, as shown in Figure 5A. This finding illustrates that skill in using representations does not necessarily align with accurate conceptual understanding. However, some students continued to struggle with generating representations that matched their explanations. For instance, one student tried to explain that there was less gas in experiment 1 compared to experiment 2 using arrows to indicate gas movement, but failed to include any visual element representing the difference in gas quantity, as shown in

Figure 5B. Another student intended to explain the role of surface area, but the drawing lacked any elements reflecting or prompting observation related to the surface area, as shown in Figure 5C. These difficulties suggest that many students still lack the skill to transform abstract ideas into concrete visual representations.




*Scenario:* The same situation as in Figure 4

*Question:* Explain why the reaction in Experiment 2 proceeds faster than in Experiment 1.
Your explanation should incorporate at least two of the following representational levels: (1) macroscopic, (2) molecular, or (3) symbolic representations through description, drawings,

A — *Answer:* The higher concentration of HCl in Experiment 2 compared to Experiment 1 results in more frequent molecular collisions, leading to a faster reaction.

B — *Answer:* Because the concentration of HCl is higher, the reaction occurs faster.

C — *Answer:* Because the concentration of the reactants in Experiment 2 is higher than in Experiment 1.

**Figure 6.** Examples of Students' Responses in Connecting Representations with Chemical Concepts (AS5)

Finally, a notable insight into students' ability in AS5 was drawn from the same scenario as AS3, as shown in Figure 4, with the question shown in Figure 6. The results revealed that students with a high ability to connect representations with chemical concepts could integrate the chemical ideas they aim to explain, such as attributing a phenomenon to changes in concentration, with at least two levels of representation. For example, they could describe the behavior of molecules at the microscopic level while also referring to macroscopic phenomena observable to the naked eye, such as the inflation of a balloon, as shown in Figure 6A. Students with a moderate ability to connect representations could link chemical concepts to only one level of representation, as shown in Figure 6B. However, most students struggled to link chemical ideas across multiple levels of representation. Very few students integrated symbolic representations, indicating either a limited understanding of the role of chemical symbols and equations or a lack of confidence in using them. Furthermore, while many students could identify relevant chemical concepts, such as the relationship between reactant concentration and reaction rate, they often failed to clearly explain the underlying mechanisms, as shown in Figure 6C. This suggests a superficial understanding of chemical processes. Although students demonstrated foundational skills in using chemical representations, they continued to hold significant misconceptions and struggled to integrate ideas across different representational levels. These findings highlight the need for instructional approaches that explicitly address conceptual misunderstandings, foster connections among multiple representation levels, and develop students' scientific reasoning and communication skills in a holistic manner.

As indicated by the results, the analysis clearly shows that most students demonstrated a moderate level of representational competence. This could perhaps be due to their moderate mastery of the subject matter reflected in their scores in the midterm examination. However, earlier teaching may not have introduced the student to the use of different types of representations. The lack of emphasis on developing skills to use the representations effectively has resulted in students having only an inadequate experience in using them, hence developing a moderate level of competence. As mentioned by Sim and Daniel (2014) and Herunata et al. (2021), representational competence correlates with both students' conceptual understanding and their ability to use chemical representations. It follows, therefore, that students cannot demonstrate a high level of representational competence with an understanding of the content alone but must also be proficient in using the various representations. This suggests that if students lack conceptual understanding, they are unlikely to demonstrate representational competence. This reflects a learning experience that may have been misaligned, emphasizing rote memorization rather than meaningful understanding, application, and the development of representational skills across diverse contexts. Without sufficient practice in using representations at the symbolic, microscopic, and macroscopic levels, students are less likely to achieve deep understanding, which in turn limits their representational competence (Santos & Arroio, 2016; Pande & Chandrasekharan, 2017; Talanquer, 2022). Within the Thai educational context, in similarity to international trends, chemistry instruction still predominantly emphasizes rote memorization rather than fostering deep conceptual understanding. There remains a lack of emphasis on cultivating students' representational competence skills (Popova & Jones, 2021; Wichaidit &Wichaidit, 2021). Most chemistry instructors do not explicitly address how students can integrate macroscopic, microscopic, and symbolic representations (Chonkaew et al., 2019). These findings highlight the importance of teaching chemistry to improve representational competence alongside conceptual understanding. This includes providing structured opportunities for students to engage with and translate between multiple forms of representation (Stieff et al., 2016; Avargil & Piorko, 2022).

The majority of students accurately described macroscopic properties, microscopic traits, and symbolic representations. Nonetheless, this certainly indicates a superficial comprehension rather than deep representational competence. While these results are consistent with the findings of Madden et al. (2011), who reveal students to be generally more successful in interpreting representations, it suggests that students may be relying on single modes of representation at each level, without bridging representations across levels. It is likely that this reliance on memorization may be exacerbated by instructional practices that focus less on making conceptual connections. Although students provided foundational explanations, when asked to link representations to underlying concepts, their connections remained tenuous at best. As highlighted by Kozma and Russell (2005), a successful explanation is dependent on meaningful interpretation, in which children have only mediocre proficiency. These findings underscore the importance of teaching strategies that encourage deeper integration of representations in the context of chemistry education.

The findings indicate a substantial deficiency in the students' capacity to associate chemical representations with fundamental concepts, thereby underscoring the difficulties encountered in linking various representations with essential chemical principles. Generally, students who possess a comprehensive understanding of chemical concepts can connect a single idea across different representational forms. When prompted to transition between various representations of the same subject, this exercise can effectively illuminate whether they harbor misconceptions or possess a genuine comprehension of the pertinent chemical concepts. Although midterm examination outcomes suggest moderate conceptual development, it appears that current pedagogical practices and learning activities do not adequately cultivate the necessary skills to connect Johnstone's three levels of representation, namely macroscopic, microscopic, and symbolic (Ghafar, 2023). This uneven progression in representational skills impedes further advancement in chemical understanding.

Moreover, the participating students demonstrated only moderate ability in connecting representations within the same level and across multiple levels. Gilbert and Treagust (2009) emphasize that teaching strategies focusing on a single type of representation, without explicitly guiding students to integrate these into a comprehensive understanding, hinder the recognition of relationships between representations and their underlying concepts. Students' struggles are particularly evident when transforming representations between levels (such as from macroscopic to submicroscopic or symbolic), which is critical for meaningful learning in chemistry (Gkitzia et al., 2020). The inability to effectively represent submicroscopic aspects contributes to difficulties in solving problems that involve macroscopic phenomena and symbolic representations (Ling et al., 2024).

Remarkably, the finding that students exhibit the lowest ability to connect multiple representations when drawn from underlying chemical concepts suggests a substantial deficiency in representational competence, which is critical to meaningful chemistry learning. This may point to the fact that learners will struggle not only with the interpretation of individual representations (symbolically, particulate, or macroscopic) but also with translating and integrating them to develop conceptual understanding. These limitations have also been established in past research, where students tend to use representations in isolation rather than collaboratively as a tool for reasoning (Kozma & Russell, 2005; Gilbert & Treagust, 2009). Moreover, textbooks have been shown to influence and inform the teachers' selection of representations and those they use in teaching, which may lead to more obstacles for students when the content does not contain multiple varied and translated representations (Bergqvist & Chang Rundgren, 2017; Gurung et al., 2022). This finding indicates that urgent and concrete pedagogical interventions are the next step, specifically in ways that build on the reconstruction models of learning. Researchers have called for the use of representational learning models to guide instruction (Ainsworth, 2006). Using representation-based learning models makes explicit the teaching of the four forms of representation and scaffolding the transformations between representations, i.e., moving thoughts from symbolic to particulate level, or observing tasty donuts (macroscopic) and linking to particles/ components. Therefore, incorporating strategies that purposefully build representational fluency is important. For example, teachers using guided-inquiry with visualizations; scaffolded integration methods about "translations" between representations i.e., physical foot/hand movement, and using animated dynamic representations or simulation-based tools (Tasker & Dalton, 2008; Ismail et al., 2025); or meta-representational discussions at the start, end or when talking about specific representations where students are encouraged to think critically about the individual purpose, strengths and limitations of each representation, and pedagogical choice, as well as conceptual depth and transferability (Prain & Tytler, 2012). Such interventions not only target representational skills but also foster a deeper integration of chemical knowledge. Additionally, using interactive multimedia that combines macroscopic, microscopic, and symbolic representations can effectively enhance students' representational competence (Wang et al., 2022; Nelsen et al., 2024). Equally essential is the strengthening of teachers' pedagogical content knowledge and their understanding of scientific models to support more effective instruction and improve student learning outcomes.

## CONCLUSION

Representational competence is crucial for deep understanding and long-term retention of chemical knowledge. This study found that most students demonstrated moderate competence, some showed low competence, and none reached a high level. Even though students could interpret and translate scientific representations to some extent, they had difficulty connecting these representations to core chemical concepts. This highlights a significant gap in how well students integrate concepts, which is reflective of broader challenges in the Thai education system, where learning often focuses more on memorization rather than fostering a meaningful understanding of the material. To address these challenges, this study proposes targeted strategies for learning development. First, chemistry curricula should clearly incorporate representational learning outcomes, ensuring that students are regularly engaged in interpreting, translating, and linking representations at the macroscopic, submicroscopic, and symbolic levels. Second, teacher professional development programs must include training in representational pedagogy, equipping educators with both theoretical knowledge and practical techniques to help students navigate multiple representations effectively. Third, the utilization of interactive learning media, such as dynamic simulations, augmented reality tools, and visual scaffolds based on Thai cultural or environmental contexts, can make abstract chemical phenomena more understandable and engaging. The findings have significant implications for chemistry education in Thailand. Improving representational competency not only aids conceptual understanding but also corresponds with the country's larger educational aims of promoting scientific literacy and educating students for real-world problem-solving in areas like sustainability and public health. Future research should examine the impact of specific instructional approaches, such as guided translation tasks or digital visualization tools, through experimental designs. Such work can inform effective strategies to promote deeper, transferable learning in science.

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